# APPLICATION OF REMOTELY SENSED DATA TO A GEOGRAPHIC INFORMATION SYSTEM FOR MICROCLIMATE CHANGE ANALYSIS

By

JONATHAN DAVID JORDAN

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To my parents,

Don and Dorothy Jordan

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APPLICATION OF REMOTELY SENSED DATA TO A GEOGRAPHIC INFORMATION SYSTEM FOR MICROCLIMATE CHANGE ANALYSIS

By

Jonathan David Jordan

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Chairman: Sun F. Shih
Major Department: Agricultural Engineering

This study demonstrates the monitoring of surface temperature pattern impacts of meso-scale changes in land-cover and hydrology through the use of a geographic information system (GIS) incorporating remotely sensed data. Advanced Very High Resolution Radiometer (AVHRR) thermal-infrared images, land-cover maps, and soil-type maps were assembled as GIS database layers for a 1-km spatial resolution study of Florida. Seasonal and diurnal surface temperature patterns of many combinations of land-cover and soil type were analyzed quantitatively. Effects of changes in land-cover and hydrology due to both artificial (agriculture, urbanization, wetland disturbance, and exotic-plant introduction) and natural factors (drought, freeze, and hurricane) were studied.

The thermal-infrared images were calibrated to at-satellite radiant temperature and geographically corrected for importation into the GIS, then corrected for atmospheric

effects and surface emissivity to produce surface kinetic temperature. Seven soil types (from maps) and 32 land-cover types (from maps, aerial photographs, and site visits) were imported into the GIS as digitized polygons.

Results of analyses performed using the GIS indicated that both land-cover and soil type, as well as soil moisture and season, were significant factors influencing surface temperature patterns in Florida. Surface temperature effects (daytime "heat island", nighttime "cold island", and diurnal variation "extreme island") of several agricultural and urban soil type/season combinations matched or exceeded those found among natural land-cover types. The surface temperature effects of certain agricultural soil type/season combinations matched or exceeded those of urban counterparts. Drought, freeze damage, hurricane damage, wetland disturbance, and exotic-plant introduction all produced significant changes in surface temperature.

# INTRODUCTION

Surface temperature is a parameter relevant to many fields. It is in demand for studies and models of climatology, hydrology, agriculture, and forestry. There are difficulties to be overcome in obtaining and applying surface temperature data, which might be solved with new techniques involving remote sensing and geographic information systems (GIS). These matters are discussed below, with emphasis on their importance to the state of Florida.

## Purpose and Objectives

The purpose of this research was to use satellite imagery together with a geographic information system to quantitatively investigate the kilometer-scale relationship between changes in land cover and those in surface temperature. The specific objectives were 1) to obtain remotely sensed thermal-infrared data at 1-km spatial resolution for the state of Florida, using the National Oceanic and Atmospheric Administration (NOAA) Television Infrared Observation Satellite (TIROS) Advanced Very High Resolution Radiometer (AVHRR) thermal-infrared imagery; 2) to calibrate this thermal-infrared data to at-satellite radiant temperature and to geographically correct the resulting temperature imagery for inclusion in a GIS; 3) to calculate

surface kinetic temperature from at-satellite radiant temperature through atmospheric correction and emissivity correction; 4) to digitize land-cover and soil-type data (obtained from maps, aerial photography, and site visits) into polygons for inclusion in a GIS; 5) to build a GIS database containing as coverage layers the surface temperature images, soil type, land-cover (natural, agricultural, urban, and industrial types), and special condition (drought, hydrologic disturbance, freeze-damage, storm-damage); 6) to utilize the GIS database in performing a quantitative analysis of seasonal and diurnal relationships between land-cover, soil type, and surface temperature; and 7) to utilize the GIS database in performing a quantitative analysis of seasonal and diurnal relationships between changes in land-cover type and changes in surface temperature.

There were two additional objectives to supplement the AVHRR work. These were 1) to perform a historical (1979) surface temperature study of Florida based on the at-satellite radiant temperature data of the National Aeronautics and Space Administration (NASA) Heat Capacity Mapping Mission (HCMM) satellite, and 2) to perform a ground-based evaluation of the DSTV/soil moisture relationship for both mineral and organic soil types.

## Importance of Surface Temperature in Climatology

Surface temperature is one of critical parameters of climate at macro-scale, meso-scale (Davis and Giles, 1990;

Giorgi and Mearns, 1991; Barron, 1992, Lewis and Wang, 1992; McCabe and Wolock, 1992), and micro-scale (Auer, 1978; Lewis, 1984; Rourke, 1985; French and Krajewski, 1994). Macro-scale climate (100 km to global spatial resolution, multi-year temporal resolution) includes the basic macroclimate, or "average weather", with its global weather systems, atmospheric/oceanic/topographic influences, and long-term perturbations from factors such as the El Niño/Southern Oscillation (ENSO), volcanic dust plumes, and greenhouse gases (McClain et al., 1985; Harries, 1990; Mather and Sdasyuk, 1991). Macro-scale climate is not directly concerned with near-surface (< 2 m above surface) processes (Akin, 1991).

Meso-scale climate (1 to 100 km spatial resolution, 1 day to 1 year temporal resolution) includes local weather and is directly concerned with near-surface processes (Henderson-Sellers and Robinson, 1986; Harries, 1990; Hostetler and Giorgi, 1993; Johannessen et al., 1993). Micro-scale climate (1 km or finer spatial resolution, 1 day or finer temporal resolution) is directly concerned with highly localized effects, which are nested within (and do not influence) the meso-scale climate (Henderson-Sellers and Robinson, 1986; Harries, 1990; Akin, 1991).

Meso-scale is the smallest scale at which surface factors have potential to force weather patterns; land-cover and/or surface moisture organized at this scale produces an organized atmospheric response (Shuttleworth, 1991). This response includes air convection and turbulence (Henderson-Sellers and

Robinson, 1986), and even shifts in rainfall patterns due to urban "heat-islands", irrigated-desert "oases", drained-marsh "heat-plateaus", etc. (Auer, 1978; Dickinson, 1988; Abtew and Khanal, 1994). In combination with soil moisture and acidity, surface temperature controls soil-biogenic greenhouse-gas emissions (Schimel et al., 1988; Yienger and Levy, 1994). Due to these effects on weather patterns and greenhouse gas emission, surface temperature is a meso-scale parameter which must be linked to the current macro-scale global-circulation models for further study of the global-change/greenhouse-effect (Bolin, 1988; Risser et al., 1988; MacCracken et al., 1990; Mather and Sdasyuk, 1991).

## Importance of Surface Temperature in Hydrology

Surface temperature is an important parameter of surface hydrology and its components such as evapo-transpiration (ET) and soil moisture (Soer, 1980; Haan et al., 1982; Heimberg et al., 1982; Price, 1984; Reiniger and Seguin, 1986; Ottlé et al., 1989; Sucksdorff and Ottlé, 1990; Novak, 1991; Rodriguez-Iturbe et al., 1991a, 1991b; Brutsaert and Parlange, 1992; Chang et al., 1992; Nikolaidis et al., 1993; Zelt and Dugan, 1994). It is also an important factor in water conservation topics such as lake and reservoir evaporation (Miller and Millis, 1989; Hondzo and Stefan, 1991; Steinhorn, 1991; Mahrer and Assouline, 1993), streamflow (Cayan, 1993), and effects of oil spills on ocean evaporation (Mather and Sdasyuk, 1991).

A typical application of surface temperature in hydrology is in the computation of the Bowen ratio (Linsley et al., 1982):

$$\beta = 0.00066\ p\ (T_s - T_a)\ /\ (e_o - e_a) \qquad [1]$$

where $\beta$ is the ratio of sensible heat transport to latent heat transport, p is the atmospheric pressure (mbar), $T_s$ is the surface temperature, $T_a$ is the air temperature (C), $e_o$ is the air saturation vapor pressure (mbar) at $T_s$, and $e_a$ is the air vapor pressure (mbar). The Bowen ratio is used in the study of reservoir evaporation and vegetation evapotranspiration (Linsley et al., 1982).

## Importance of Surface Temperature in Agriculture and Forestry

Surface temperature is important to agriculture and forestry as a factor of water-stress and growing-region for crops and trees (Henderson-Sellers and Robinson, 1986; Seguin, 1989). Meso-scale surface temperature is of interest to studies involving agricultural topics such as regional crop condition and yield prediction (Idso et al., 1979, 1981; Reginato, 1983; Taconet et al., 1986b; Hope and Jackson, 1989). It is a major factor involved in soil conservation issues--such as soil subsidence (Lucas, 1982) and soil degradation (Kilmer, 1982), which are critical to long-term agricultural planning. Surface temperature is also of

interest in the assessment of forest-fire risk (Waters, 1976; Chuvieco and Martin, 1994).

Together with soil moisture, meso-scale patterns and changes of surface temperature are a major factor in outbreaks of pests, parasites, and diseases in agricultural crops, forest trees, and livestock (Uvarov, 1931; Geiger, 1950; Akin, 1991). Examples of such impacts include locust swarm-behavior, Dutch elm disease, chestnut blight, tobacco blue mold, Japanese beetle, Colorado potato beetle, potato blight, cotton leaf worm, seedling-scald, and liver fluke (Uvarov, 1931; Rourke, 1985; Akin, 1991).

## Factors Affecting Surface Temperature Patterns

Land surface temperature patterns at meso-scale are forced by several factors which can change spatially and temporally (Hillel, 1980; Risser et al., 1988; Lewis and Wang, 1992). These include macro-scale climate, solar irradiation, geothermal heat sources, maritime effects, orogenic effects, vegetation transpiration, root-zone soil moisture, soil type, and land cover type.

Macro-scale climate has been discussed previously; its impact on meso-scale surface temperature takes the form of annual cyclic changes in average values of precipitation and air temperature, which are well-documented for most places. The macro-scale climate effect on surface temperature can be estimated from comparison of data from similar natural land-cover type pairs across macro-scale climate zones (temperate-

zone pine forest and subtropical-zone pine forest, temperate-zone marsh and subtropical marsh, etc.). Advection effects (strong winds, precipitation, etc.) from transient weather phenomena such as storms, winter frontal systems, and especially desert-winds (harmattan, etc.) can have a substantial impact on meso-scale temperature (and relative-humidity), but these effects are sporadic and transient outside of continental interiors (Hillel, 1980; Haan et al., 1982), and are not addressed in this study. Solar irradiation influences surface temperature through daily cyclic changes, and is a primarily a function of latitude, date, and hour. Geothermal heat sources are common at micro-scale--such as hot springs, subterranean steam-lines (Axelsson, 1988), and artesian wells (Jordan and Shih, 1988), but rare at meso-scale (volcano and geyser areas).

Maritime effects operate at micro-scale (air advection immediately adjacent to the coast) and at meso-scale (increased humidity further inland) (Henderson-Sellers and Robinson, 1986; Dickinson, 1988). The positions of meso-scale water bodies and wetlands are well documented. Florida, due to its proximity (at meso-scale) to the sea on every side, its near sea-level elevation, and its lack of topographic obstructions (mountains), is free from sources of major variation in the meso-scale maritime effect. The micro-scale maritime effect on surface temperature can be estimated from comparison of data from coastal/inland pairs of similar

natural land-cover type, such as saltmarsh and freshwater marsh, coastal hammock and inland hammock, etc.

Orogenic effects on meso-scale surface temperature can be very pronounced in mountainous regions (Atkinson, 1985; Henderson-Sellers, 1986; Barros and Lettenmaier, 1994). They are nonexistent in level-terrain regions such as Florida.

Vegetation transpiration, root-zone soil moisture, soil type, and land cover type are forcing factors of meso-scale surface temperature which are strongly inter-related. Vegetation transpiration is a daily cyclic phenomenon. Root-zone soil moisture can change over hours or days; it is artificially controlled in urban and agricultural areas, and is a function of the soil type and macroclimate in natural areas. Soil type is generally constant over time, and is documented to various degrees in most of the world; it is a particularly important surface temperature factor for cleared areas.

Land-cover type is subject to both annual cyclic changes (seasonal tree leaf cover, agricultural crop seasons) and sudden changes (agricultural/urban development, natural disasters). Land-cover type is well-documented at meso-scale for most of the world, although available maps are often overly simplistic in land-cover distinction--particularly for agricultural land-cover. Meso-scale land-cover information for application to meso-scale surface temperature work should contain distinctions comparable to Level-III designations in the United States Geological Survey (USGS) land use

classification system (Anderson et al., 1976)--for example, "pasture" or "cropland" instead of simply the Level-II "cropland and pasture" or Level-I "agriculture" designations.

Temperature Impacts of Changes in Land-Cover

Land-cover is a forcing factor of surface temperature pattern which can experience meso-scale changes that are non-cyclic and discontinuously-distributed both spatially and temporally. These changes can be due either to natural causes (volcanoes, storms, floods, droughts, wildfires, pests, etc.) or artificial causes (related to agricultural and urban/ industrial development). International attention has mounted in recent years concerning the worldwide extent of deforestation (Mather and Sdasyuk, 1991), compared to the very few regions currently experiencing a significant degree of reforestation (Ireland, Senegal, England, and Algeria as of 1984).

Urban effects. Previous research has established the concept of the urban heat island, which is characterized by increased surface and air temperature (by 5 to 10 C) and decreased relative-humidity in an urbanized area relative to its surroundings (Eagleman, 1974; Lewis, 1984; Atkinson, 1985; Balling and Brazel, 1988; Henry et al., 1989; Akin, 1991). The more high buildings, more smog, and fewer trees, the more pronounced the effect (Henderson-Sellers and Robinson, 1986). The heat island is primarily a daytime effect within the urbanized area, and has been shown to have a cellular

topology, rather than a smooth dome shape, due to the peak and canyon geometry of the urban skyline (Atkinson, 1985). There is a similar, but lesser, nighttime heat-island effect (Eagleman, 1974; Henry et al., 1989). The importance of urban temperatures to human well-being has been noted (Lewis, 1984; Henderson-Sellers and Robinson, 1986; Meerow and Black, 1988).

There is a need for more detailed investigation of the heat island effect. The heat island of urban areas has usually been compared simply to non-urbanized areas nearby; the influence of soil type has often been ignored. Thus, it may be that a well-drained soil area selected for urban use has always had an associated heat island relative to surrounding areas of different soil type, even under its natural cover. In addition, there is the possibility that the inclusion of water-bodies, as is common in certain Florida suburbs (finger canals) and mines (tailings ponds), may counteract the urban heat island effect. The presence of windbreak trees, as in golf-course suburb communities, restricts the lateral flow of near-surface air, leading to higher daytime temperatures in the open area between trees than would be the case for a completely open field (Geiger, 1950; Crowe, 1971; Meerow and Black, 1988a; McCarty et al., 1990). In closed-canopy parkland, the removal of undergrowth and low tree branches increases the lateral flow of near-surface air, producing a moderating effect on temperature compared to open urban areas, but a decrease in humidity compared to a natural forest (Lewis, 1984).

Agricultural effects. Agricultural effects on surface temperature patterns have received less attention than urban effects, which is undeserved, considering the vastly greater areal extent of agricultural land-cover compared to urban land-cover. For irrigated areas in deserts, a measurable daytime oasis effect characterized by decreased surface and air temperature and increased relative-humidity compared to the surroundings has been noted (Hillel, 1980; Haan et al., 1982; Henderson-Sellers and Robinson, 1986). For agricultural land-cover in forest/wetland areas, a measurable daytime heat-plateau effect characterized by increased surface and air temperature and decreased relative-humidity compared to the natural surroundings has been observed (Ghuman and Lal, 1987), together with a corresponding nighttime cold-plateau of decreased surface and air temperature compared to the natural surroundings (Chen, 1979). The presence of belt-planted trees, as in agricultural field windbreaks, restricts the lateral flow of near-surface air, leading to higher daytime temperatures in the open area between trees than would be the case for a completely open field (Geiger, 1950; Crowe, 1971; Meerow and Black, 1988a; McCarty et al., 1990).

Florida land-cover change. In Florida, natural causes of meso-scale land-cover change have consisted of storms (hurricanes), droughts, wildfires, and freezes. Artificial factors of land-cover change have consisted of agricultural development, urban development, industrial development, water-

control projects, naturalization projects, and invasion by exotic vegetation.

Agricultural development in previous times (pre-Columbian to early 1900s for panhandle and north; primarily from 1910 to 1950 for south) displaced much of the natural land-cover in Florida (Fernald and Patton, 1984); in recent times it has consisted primarily of changes in the type of agriculture--especially between row-crops, pasture, and citrus orchard--on the same land. Urban/industrial development in previous times (primarily in the form of urban centers and strip mines) displaced much of the natural and agricultural land-cover; in recent times this development is continuing--particularly in the form of suburbs.

Water-control projects are located in the Everglades Agricultural Area (EAA), Kissimmee River basin, and Upper Suwannee River basin (north-central Florida as well as south-central Georgia). Naturalization projects include the restoration of marshes (Payne's Prairie, Lake Apopka, Kissimmee River basin, Lake Jessup, and the activity of beavers naturally re-colonizing parts of the panhandle), saltmarshes (Indian River Lagoon, Tampa Bay), and scrub (state parks, local parks, and Archbold Biological Station). In addition, efforts have begun in recent decades to reclaim mined land for naturalization and even agriculture (Blakey, 1973).

Invasion by exotic vegetation has occurred at meso-scale in south Florida (EPPC, 1990). This vegetation consists of

evergreen trees which have a very fast growth rate, and transpire enough to decrease the root-zone soil moisture--which is precisely why some of them were introduced in earlier decades--to dry out wetlands (EPPC, 1990). The spread of exotic forest has been beyond effective human control since the 1950s (Barrett, 1956; EPPC, 1990), and has now reached proportions of serious ecological and hydrological concern to south Florida.

<u>Temporal Inter-Relation of Forcing Factors</u>

The net surface energy flux, soil type, and root-zone soil moisture are forcing factors of the surface temperature pattern which are inter-related temporally (Geiger, 1950; Crowe, 1971; Kahle, 1977; Hillel, 1980; Bolin, 1988; Pollak, 1992). A bare-soil, flat-terrain, conductive heat-transfer (non-advective) surface energy balance can be modeled temporally by the harmonic equation (Mulders, 1987):

$$T(z,t) = T_{avg} + [F_o/(P\omega^{1/2})]e^{-z/d}\sin(\omega t - z/d - \pi/4) \qquad [2]$$

where $T(z,t)$ is the soil temperature (K) at depth <u>z</u> (m) and time <u>t</u> ($t = 0$ s at 0000 h) expressed as local solar time (LST), $T_{avg}$ is the average (treated as constant) soil temperature (K) at a depth of 2 to 3 m, $F_o$ is the amplitude (W $m^{-2}$) of the net surface energy flux F, P is the soil thermal inertia (J $m^{-2}$ $K^{-1}$ $s^{-1/2}$), <u>d</u> is the damping depth (m), and $\omega$ is the Earth angular rotation frequency ($7.27\text{x}10^{-5}$ $s^{-1}$). The net

surface energy flux, modeled in the form $F = F_o \sin(\omega t)$, is primarily a function of solar irradiation and near-surface air temperature (Budyko, 1974; Henderson-Sellers and Robinson, 1986; Lewis and Wang, 1992). Soil thermal inertia is expressed by the formula (Price, 1982):

$$P = (\lambda \rho c)^{1/2} \quad [3]$$

where $\lambda$ is the soil thermal conductivity (W $m^{-1}$ $K^{-1}$), $\rho$ is the soil density (kg $m^{-3}$), and $\underline{c}$ is the soil heat capacity (J $kg^{-1}$ $K^{-1}$). The components $\lambda$, $\rho$, and $\underline{c}$ are directly related to the soil moisture content for a given soil type (Lillesand and Kiefer, 1979; Carlson et al., 1981; Price, 1984; Curran, 1985). Therefore, the higher the soil moisture content, the warmer the soil temperature during the night and the cooler the soil temperature during the day, as has been noted in numerous studies (Shih et al., 1986; Taconet et al., 1986b; Sugita and Brutsaert, 1992). The above equation can be solved for surface temperature, $T_s$, yielding the equation (Mulders, 1987):

$$T_s(t) = T_{avg} + [F_o/(P\omega^{1/2})]\sin(\omega t - \pi/4) \quad [4]$$

where the quantities are described as before. The $\pi/4$ term translates (by $2\pi$ = 24 h) to a 3-hour time lag between maximum $F_o$ (1200 h LST) and maximum surface temperature (1500 h LST). Non-conductive components of soil heat transfer (dew evaporation) can cause the surface temperature to vary

somewhat from that indicated by equation 4 (Hinkel and Outcalt, 1993), but only for a short period in the early morning (Schmugge, 1978; Price, 1982).

Diurnal surface temperature variation. Taking the diurnal surface temperature variation (DSTV) of equation 4 leads to the equation (Mulders, 1987):

$$DSTV = T_{max} - T_{min} = 2\ F_o/(P\omega^{1/2}) \qquad [5]$$

where $T_{max}$ is the maximum surface temperature (K) at t = 1500h LST, $T_{min}$ is the minimum surface temperature (K) at t = 0300h LST, and P, $\omega$, and $F_o$ are defined as before. Thus, DSTV is inversely related to the root-zone soil moisture content, and is a strong indicator of relative root-zone soil moisture conditions for different locations of the same soil type on the same day (Engman and Gurney, 1991). The fact that DSTV is an indicator of daily-average root-zone soil moisture makes it particularly useful to hydrologic modeling studies (Parlange et al., 1992). The presence of a clay hardpan or bedrock within the root-zone depth of shallow soils will lead to deviations from the predicted DSTV of equation 5 (Hillel, 1980). This influence of foreign bodies within the root-zone soil depth on DSTV has in fact been used at micro-scale to locate buried objects/features such as abandoned mine tunnels and bombs (Cloud, 1992).

Estimated seasonal DSTV. Seasonal values of bare-soil DSTV can be estimated based on soil parameters. A typical

Florida value of $F_o$ in summer is 0.003941 (cal $cm^{-2}$ $s^{-1}$) and in winter is 0.001433 (cal $cm^{-2}$ $s^{-1}$) (ASHRAE, 1981). For a mineral soil (sand or clay with typical 40% porosity), the value of $\rho c$ is 0.3 (cal $cm^{-3}$ $K^{-1}$) under dry condition and 0.7 under saturated condition, and the value of $\lambda$ is 0.0007 (cal $cm^{-1}$ $s^{-1}$ $K^{-1}$) under dry condition and 0.0052 under saturated condition (Hillel, 1980). For an organic soil (peat with typical 80% porosity), the value of $\rho c$ is 0.35 (cal $cm^{-3}$ $K^{-1}$) under dry condition and 1.15 under saturated condition, and the value of $\lambda$ is 0.00014 (cal $cm^{-1}$ $s^{-1}$ $K^{-1}$) under dry condition and 0.0012 under saturated condition (Hillel, 1980). Plugging these values into equations 3 and 5 produces estimated summer DSTV (K) ranging from 15 (saturated) to 64 (dry) for mineral soil, and from 25 (saturated) to 132 (dry) for organic soil; it produces estimated winter DSTV (K) ranging from 6 (saturated) to 23 (dry) for mineral soil, and from 9 (saturated) to 48 (dry) for organic soil. Agricultural land-cover values of DSTV can be expected to lie somewhere between those of the saturated condition and those of the totally dry condition.

Relevant depth of surface temperature/soil moisture relation. The depth of soil to which the soil moisture content is relevant to the surface temperature is a function of the damping depth, d, which is given by the equation (Hillel, 1980):

$$d = [2\lambda/\rho c\omega)]^{1/2} \qquad [6]$$

where $\lambda$, $\rho$, $\omega$, and c are defined as before. The values of $\lambda$, $\rho$, and c are functions of both soil moisture and soil type. For a mineral soil (sand or clay with typical 40% porosity) under a totally-dry condition, the value of d is about 8 cm; for an organic soil (peat with typical 80% porosity) under a dry condition, the value of d is about 3 cm (Hillel, 1980). The attenuation factor of equation 2 is $e^{-z/d}$, so that an attenuation $(100 - e^{-z/d})$% of 95% (relevant depth limit for estimated soil-moisture) is reached at a depth of 3d, corresponding to 24 cm for a mineral soil and 9 cm for an organic soil. Under saturated soil condition, the value of d increases to about 14 cm for mineral soil and about 5 cm for organic soil (Hillel, 1980), increasing the respective relevant depth limits to 42 cm and 15 cm. The moisture content of such root-zone depths is of importance to surface hydrologic modeling (Rourke, 1985; Risser et al., 1988; Milly, 1994; Zelt and Dugan, 1994) and climatological modeling (Gillies and Carlson, 1994; Salvucci and Entekhabi, 1994; Smith et al., 1994).

Vegetation influence on DSTV. Vegetated land cover affects both the maximum and minimum surface-temperature components of DSTV (Geiger, 1950; Luval et al., 1990). Minimum surface temperature is raised by nighttime reflection of soil-emitted energy back to the surface. The radiation contribution from vegetation foliage at night is negligible--foliage quickly reaches equilibrium with air temperature (Hillel, 1980; Chen et al., 1982; Reiniger and Seguin, 1986;

Seguin, 1989; van de Griend and van Boxel, 1989). The nighttime vegetation effect will decrease during winter for deciduous vegetation species.

Maximum surface temperature is lowered by the daytime evapotranspiration (ET) from vegetation. ET rate is a function of vegetation type (exact species or cultivar), ambient water-vapor pressure deficit, air temperature, vegetation species, and vegetation water stress (Idso et al., 1981a, 1981b; Wetzel et al., 1984; Reiniger and Seguin, 1986; Taconet et al., 1986a, 1986b; van de Griend and van Boxel, 1989; Doyle, 1992). It should be noted that the transpiration component of ET is present for most vegetation only from late morning to afternoon (Bolin, 1988). If the source of vegetation water stress is limited to root-zone soil moisture (rather than salinity or damage from pests, diseases, wind, hail, etc.), and the other ET factors are measured, the soil moisture condition can be calculated. The relevant depth in this case is dependent on the vertical distribution of the root system (according to plant species and maturity), not on the $\underline{d}$-value of equation 6 (Rubin and Or, 1993). This relation is the basis for the Crop Water Stress Index (CWSI), which is widely used for scheduling the irrigation of agricultural fields (Howell et al., 1983; Reginato, 1983; SOEMC, 1987; EI, 1991). Again, the daytime vegetation effect will decrease during winter for deciduous vegetation species.

The diurnal effect on the net heat flux of the vegetated surface, G (W $m^{-2}$) can be represented (for a non-advective

situation) in form (Haan, 1982):

$$G = F_o \sin(\omega t) - LE \qquad [7]$$

where LE is the latent heat flux (W $m^{-2}$) caused by the vegetation. The term LE can be approximated using the Bowen ratio, $\beta$, producing the equation (Haan, 1982):

$$LE = \frac{F_o \sin(\omega t)}{1 + \beta} \qquad [8]$$

where $\beta$ typically ranges from 0.1 to 0.3 for humid-climate conditions. Assuming $\beta$ = 0.2, and substituting the LE from equation 8 into equation 7, it follows that the DSTV for the vegetated surface, $DSTV_v$ is

$$DSTV_v = (0.3334)\ F_o/(P\omega^{1/2}) \qquad [9]$$

which is a reduced-amplitude version of equation 5. The assumption of full canopy closure is made here; the estimation of exact effects of partial canopy (as in many forms of agricultural land-cover) are a complex matter for study at very fine spatial and temporal scales (Taconet et al., 1986a, 1986b; Massman, 1992).

Spatial Inter-Relation of Forcing Factors

The soil type, root-zone soil moisture, and land-cover type are forcing factors of the surface temperature pattern which are inter-related spatially (Akin, 1991). Different

types of agriculture require the maintenance of different levels of soil moisture (Ziegler and Wolfe, 1961; Snyder, 1978; Henley, 1983; McCarty and Cisar, 1990)--standing water for rice, taro, and fish-farm; high water-table for sod-farm; medium water-table for winter-vegetables, sugarcane, potato, strawberry, blueberry, blackberry, and pasture; and relatively low water-table for leatherleaf fern, citrus, and most other fruit trees.

Likewise, different soil types require different agricultural management practices--irrigation of deep sands and loams; drainage of organic soils and marls; and both irrigation and drainage of spodosols and rockland soils (Jones, 1948; Stewart et al., 1963; Hochmuth and Hanlon, 1989). Soil type and seasonal soil-moisture levels dictate the natural land-cover type (scrub, forest, swamp, marsh, etc.) and limit the possibilities of agricultural land-cover types (citrus primarily to mineral soil, sugarcane primarily to organic soil, blueberry to acid soil, atemoya to sub-alkaline soil, etc.) (Critchfield, 1960; Schimel, 1988; Akin, 1991).

Urban development, however, is less impeded by soil type. This is particularly evident in Florida, where coastal sands, flatwoods sands, marls, and even mucks have been urbanized, as well as the more conventional deep sands, upland loamy sands, and sandy rockland.

Potential for Future Changes in Soil Type

General soil type, which is a constant forcing factor of meso-scale surface temperature for mineral-soil areas, can change for organic-soil areas, or even for mineral-soil areas where mass-wasting occurs (Risser et al., 1988). Organic soils drained for conventional agricultural use tend to subside and eventually disappear (Snyder, 1978; Kilmer, 1982; Lucas, 1982; Abtew and Khanal, 1994). This effect was well understood even at the time the EAA water-control system was being planned and implemented (Jones, 1948). The current rate of organic soil subsidence in the EAA is about 1 inch per year (Snyder, 1978); the natural temporal scale of soil type change is typically of the order of 10,000 years (Dickinson, 1988; Lucas, 1982). The potential mesoscale surface-temperature impact of such a soil-type change in Florida is greatest in the EAA, where organic soil will likely be replaced in the near future by sandy/marly rockland if the agricultural land-cover does not change to aquatic crops or restored marsh.

## REVIEW OF LITERATURE

The techniques involved in the remote sensing of land surface temperature are described. Previous studies, their methods, and their results are discussed.

### Difficulties of Surface Temperature Measurement

Unlike air temperature, surface temperature cannot be interpolated between point measurements on land surfaces (due to differences in several spatially-variable factors); to obtain it synoptically at meso-scale requires some form of satellite-based radiometry. Thermal-infrared and passive-microwave radiometry are the two types applicable to the typical Earth-surface range of temperatures (Lillesand and Kiefer, 1979; Owe and Chang, 1988; Engman and Gurney, 1991). Both of these are available from various satellite platforms. Passive-microwave sensor data have the advantage of cloud penetration, but are much more limited in spatial resolution and temperature accuracy than are thermal-infrared sensor data at this temperature range, and are sensitive to extraneous factors such as surface microwave-roughness and radio-communication interference (Lillesand and Kiefer, 1979; Owe and Chang, 1988; Harries, 1990; Engman and Gurney, 1991; Owe et al., 1992). Passive microwave data are typically used at meso-scale (from satellite platform) for ice/snow water-

content mapping (Mather and Sdasyuk, 1991) or atmospheric sounding (Miller et al., 1994), or at micro-scale (requiring an aircraft platform) for surface temperature or soil moisture mapping (Ijjas and Rao, 1992; Appleby et al., 1993; Paloscia et al., 1993). Due to the above considerations, thermal-infrared radiometry was selected as the source of surface temperature data in this study.

The extraction of land surface temperature data from satellite thermal-infrared radiometer measurements involves three different processes--sensor calibration, atmospheric correction, and emissivity correction. Errors incurred in any of these processes will degrade the accuracy of the surface temperature data (Marlatt, 1967; Llewellen-Jones et al., 1984; Schott, 1989; Ben-Dor et al., 1994). Each satellite-based thermal-infrared sensor has its own level of radiometric precision and its own standardized calibration technique, which the user must consult (Wolfe and Zizzis, 1978; Tebo, 1994a). A typical order of magnitude of radiometric precision for thermal-infrared radiometers is 0.1 C (Myhre et al., 1988; NOAA, 1991).

Ignoring the atmospheric correction can result in surface temperature underestimates of up to 20 C (Llewellyn-Jones et al., 1984; Price, 1984; Sobrino et al., 1991); this source of error is primarily of concern in comparison of surface temperatures from more than one time or date (in addition, substantial spatial variation in the atmospheric effect can be expected for images covering continental distances). Ignoring

emissivity correction over land surfaces can result in underestimates of up to 10 C (Barton and Takashima, 1986); these errors will vary spatially within an individual image--resulting in an inability to accurately compare the surface temperature of one location to the next. Therefore, if atmospheric or emissivity corrections are not used, the remotely-sensed surface temperatures may be in error (conservative) by at least two orders of magnitude compared to the sensor radiometric precision.

## Atmospheric Correction Techniques

Atmospheric correction is needed for remotely sensed thermal data, due to the combined effects of absorption, scattering, and in-path radiance by the atmosphere upon thermal-infrared imagery, even in "atmospheric window" bands (Lillesand and Kiefer, 1979; Ben-Dor et al., 1994). The net effect on satellite thermal-infrared radiometry is an attenuation. Three general types of atmospheric correction techniques have been developed.

Atmospheric modeling. Detailed modeling of the atmosphere has been used successfully for atmospheric correction of thermal-infrared data (Henry et al., 1989; Wukelic et al., 1989; Luval et al., 1990; Gillies and Carlson, 1994; Sadot et al., 1994). It requires atmospheric data, which in most instances has been provided by radiosondes, although laser-based techniques are currently being developed for this purpose (Tebo, 1994b). Atmospheric sensor

instruments exist on most current satellite platforms, but these have very crude spatial resolution and are used for global atmospheric research rather than meso-scale atmospheric modeling (Zhang, 1993; Aumann and Pagano, 1994; Ellingson et al., 1994). The collection of atmospheric data by radiosondes is relatively expensive, and cannot be substituted with non-local radiosonde data, non-simultaneous radiosonde data, or estimated atmospheric values (Kerr et al., 1992).

Split-window techniques. Empirical "split-window" techniques, based on differential atmospheric absorption effects in different thermal-infrared bands, have long been used successfully in atmospheric correction of thermal-infrared data (Price, 1984; Llewellyn-Jones et al., 1984; McClain et al., 1985; Cornillon et al., 1987; Cooper and Asrar, 1989; Vidal, 1991). They require a sensor that possesses multiple thermal-infrared bands, which is fortunately available from various satellite platforms. They also require ground-based surface-temperature measurements to allow the initial calculation of their coefficients, but these have already been established and reported for the individual techniques (McClain et al., 1985; Di and Rundquist, 1994). There are inherent difficulties in applying these techniques to land surface studies (Becker, 1987; Sobrino et al., 1991), the most important of which are the assumptions that the surface emissivity is homogeneous within the instantaneous field of view (IFOV) of the sensor, and that it is equal to 1. Therefore, split-window techniques are primarily restricted to

sea-surface studies, where these assumptions are usually valid.

Water-body reference technique. The water-body reference technique requires one or more large water bodies, with near-surface water temperature measurements taken simultaneously with the thermal-infrared image (Lillesand and Kiefer, 1979). These measurements must be taken for each image date and time, which can pose a logistical problem for studies involving a temporal series of images. Fortunately, such water-body data are collected and made readily available in Florida by various environmental agencies.

This technique includes the assumption that within the sensor IFOV the water-body surface temperature and emissivity (not necessarily equal to 1) are homogeneous. This assumption is generally valid. It also assumes that the water body is not under conditions such as very hot and dry (desert-climate) ambient air or strong winds, which would produce a difference between skin and near-surface bulk temperature of the water. This assumption is valid for non-desert water bodies under low wind conditions (Cornillon et al., 1987).

## Emissivity Correction Techniques

Radiant (blackbody) temperature values can be converted to kinetic (surface) temperature values if the emissivity (in the sensor bandwidth) is known with sufficient accuracy. The physical foundation for kinetic temperature calculation by

radiometry is described by the Planck function (Saito et al., 1992):

$$E(\lambda, T) = \frac{\epsilon\ C_1\ \lambda^{-5}}{\exp\ [C_2/(\lambda\ T)] - 1} \qquad [10]$$

where E is the measured energy (W $m^{-2}$ $\mu m^{-1}$), $\lambda$ is wavelength ($\mu$m), $C_1$ is a constant ($3.74 \times 10^8$ W $m^{-2}$ $\mu m^4$), $C_2$ is the Boltzmann constant (14,388 $\mu$m K), T is the kinetic temperature (K), and $\epsilon$ is the emissivity. A commonly encountered formula for kinetic temperature calculation is the Stefan-Boltzmann equation (Lillesand and Kiefer, 1979):

$$T_{kin} = \epsilon_b^{1/4}\ T_{rad} \qquad [11]$$

where $T_{kin}$ is the kinetic temperature (K), $T_{rad}$ is the radiant temperature (K), and $\epsilon_b$ is the broadband emissivity (0 to 1). However, this formula was designed for application to laboratory situations of broadband (all wavelengths) radiometry, rather than the "atmospheric window" band radiometry performed by satellite sensors (midwave thermal-infrared window at 3-5 $\mu$m, longwave thermal-infrared window at 8-14 $\mu$m). To account for this, some researchers (Davies et al., 1971; Price, 1983) have used a version of the Stefan-Boltzmann equation modified for use with longwave thermal-infrared sensor bands (Price, 1983):

$$T_{kin} = \epsilon_{lw}^{1/4.5}\ T_{rad} \qquad [12]$$

where $T_{kin}$ and $T_{rad}$ are defined as before, and $\epsilon_{lw}$ is the longwave emissivity. This modified Stefan-Boltzmann formula still contains simplifying approximations which limit its accuracy in application to remotely sensed thermal data. The integration of equation 10 over the bandwidth of given sensor provides a better formula for quantitative longwave thermal-infrared radiometry (Singh, 1985; Driggers et al., 1992; Saito et al., 1992). It is given by the equation (Singh, 1985):

$$T_{kin} = \frac{k\ CWN_i}{\ln\left[1 - \epsilon_{lw} + \epsilon_{lw} \exp(k\ CWN_i\ /\ T_{rad,i})\right]} \qquad [13]$$

where $T_{kin}$ is defined as before, <u>k</u> is the Boltzmann constant (1.43883 cm K), $T_{rad,i}$ is the radiant temperature (K) in band <u>i</u>, $CWN_i$ is the central wave number of band <u>i</u> ($cm^{-1}$), and $\epsilon_{lw}$ is the longwave emissivity. The central wave number is generally documented for each band of a given sensor.

Emissivity presents the difficulty of being a property that is calculable, rather than directly measurable (Fuchs and Tanner, 1968; Friedman, 1969; Hejazi et al., 1992). Two different methodologies have been employed to obtain emissivity for processing remotely sensed thermal image data.

<u>Emissivity by assignment.</u> This commonly used technique is based on longwave emissivity values determined in the field or laboratory from close-range, longwave thermal-infrared radiometry of small samples (Buettner and Kern, 1965; Fuchs and Tanner, 1968; Friedman, 1969; Taylor, 1979; Barton and

Takashima, 1986; Rees, 1990; van de Griend et al., 1991; Vidal, 1991; Salisbury and D'Aria, 1992). An emissivity value is then assigned to a particular sensor IFOV according to land-cover information or the normalized-difference vegetation index (NDVI) (Gervin et al., 1985; Henry et al., 1989; Kerr et al., 1992; Brown et al., 1993; van de Griend and Owe, 1993). This method is primarily limited to aircraft or ground radiometry, since the laboratory-determined emissivity values are fine-resolution quantities bearing little relation to the pixel-average emissivity value corresponding to a satellite sensor IFOV (Curran, 1985; Jupp et al., 1988; Masuda et al., 1988). An additional problem with this technique in agricultural areas is that bare sand emissivity is controlled by the moisture content of a very thin surface layer, and can change over a short period of time (Fuchs and Tanner, 1968).

Twin-band technique. The physically-based "twin-band" technique allows the calculation of pixel-average emissivity from a thermal-infrared image (Artis and Carnahan, 1982):

$$\epsilon_{ij} = \exp \{k\ (T_{rad,i}-T_{rad,j})\ /\ [T_{rad,i}\ T_{rad,j}\ (\lambda_i-\lambda_j)]\} \qquad [14]$$

where $\epsilon_{ij}$ is the emissivity over the wavelengths from band $\underline{i}$ to band $\underline{j}$, $T_{rad,i}$ and $T_{rad,j}$ are the radiant temperatures (K) in bands $\underline{i}$ and $\underline{j}$, $\underline{k}$ is the Boltzmann constant ($1.43883\text{x}10^{-2}$ m K), and $\lambda_i$ and $\lambda_j$ are the respective central wavelengths (m) of bands $\underline{i}$ and $\underline{j}$. This method requires a sensor possessing two thermal-infrared bands that are synoptic, spectrally close,

and spectrally narrow. This makes it inapplicable to the single-band thermal-infrared data acquired by most of the current satellite sensors (GOES-VISSR, Nimbus-7, Landsat-TM, Meteor). Fortunately, the twin-band requirement is met by the NOAA TIROS satellite series AVHRR sensor longwave bands 4 and 5. More sophisticated emissivity correction techniques involving three thermal-infrared bands have been developed (Hejazi et al., 1992), but few current satellites produce imagery containing triplet thermal bands (AVHRR band 3 does not form a triplet with bands 4 and 5, since it is a midwave thermal-infrared band). Such multi-band techniques will likely be the methods of choice for emissivity correction of satellite-based surface temperatures from the more advanced sensors aboard satellites of the future international Earth Observing System (EOS) program.

## Previous Studies

Previous studies involving remotely sensed land surface temperature have been hampered by various factors, including sensor limitations, lack of adequate processing techniques, lack of consideration for one or more of the surface temperature forcing factors, and lack of an adequate manipulation technique for large quantities of spatial and temporal data. In particular, there has been a longstanding difficulty in the mixing of raster (remotely sensed) data with vector (map) data in climatological studies (Mather and Sdasyuk, 1991). Consistency of procedural attention to the

various components of meso-scale land-surface temperature research needs to be improved so that individual project databases can be made mutually compatible.

Chen (1979, 1980). Chen (1979, 1980) used NOAA Geostationary Operational Environmental Satellite (GOES) Vertical Infrared Spin-Scan Radiometer (VISSR) thermal-infrared, winter, nighttime images of peninsular Florida in a multi-year, meso-scale study of the feasibility of monitoring agricultural areas for potentially crop-damaging cold temperatures. Geographic correction was performed by NOAA using satellite orbital telemetry; the resulting images required manually-fitted offsets of up to 3 pixels (VISSR thermal-infrared has 8 km nominal resolution at nadir). Emissivity by assignment was used for both agricultural and natural land-cover. Comparison of calibrated at-satellite temperatures to ground-measured surface temperatures (from hand-held thermal-infrared radiometer) and near-ground air temperatures (from thermometry) indicated a range of error of up to 5 C (for both sets of data), which nonetheless allowed for determination of statistically significant differences in temperature between broad categories of land-cover (agriculture, marsh) and soil (organic). This study indicated the potential for detailed research into meso-scale, satellite-based, land-surface temperature impacts of land-cover type and its relevance to agriculture, as well as the difficulties of image registration, and especially the

importance of full correction for both atmospheric and emissivity effects.

Cornillon et al. (1987). Cornillon et al. (1987) used NOAA TIROS AVHRR thermal-infrared images to construct an archive of quality-assured meso-scale sea-surface (Atlantic ocean) temperature maps. Geographic correction was performed based on TIROS satellite orbital telemetry data and ground-control points; accuracy of pixel registration was to the nearest 1.5 km (AVHRR has 1.1 km nominal resolution at nadir). Because entire AVHRR scans (including image extremities or "limbs") across continental distances were used, the images were corrected for scan-angle effects. Ordinarily, AVHRR longwave thermal-infrared images do not require correction for scan-angle effects (Masuda et al., 1988; Kerr et al., 1992). The water-body atmospheric correction technique was used, and verification datasets indicated an accuracy to the nearest 0.51 C for sea-surface temperatures. This study illustrated the value of accuracy assessment for both image registration and surface temperature, and the surface temperature accuracy attainable through atmospheric correction by the water-body method.

Balling and Brazel (1988). Balling and Brazel (1988) used NOAA TIROS AVHRR thermal-infrared images in a meso-scale study of the urban heat-island effect in Phoenix, Arizona. Images were geographically corrected based on satellite orbital telemetry data. No atmospheric correction procedure was reported. Emissivity correction was performed by

assignment (several values), and the Stefan-Boltzmann equation was used to compute surface temperature. A lack of GIS capability led to analyses based on linear transects of image features, rather than on areal extractions. No accuracy evaluation for geographic registration or surface temperature was reported, but statistically significant differences in urban center and suburb heat island effects were observed. This study demonstrated the feasibility of measuring the surface temperature impact of a purely meso-scale land-cover type with AVHRR images, and the need for both accuracy evaluation and a GIS-based analytical technique.

Cooper and Asrar (1989). Cooper and Asrar (1989) used NOAA TIROS AVHRR thermal-infrared images in a meso-scale study of land surface temperature in Kansas. Geographic correction was performed by NOAA using satellite orbital telemetry. No registration accuracy analysis was reported. Lack of GIS overlay-analysis capability required the use of triangulation between image features (lakes) to delineate study areas. Atmospheric correction was performed by several techniques--including both atmospheric modeling methods (with radiosonde data) and split-window techniques. Ground-based radiometer measurements of temperature were used to evaluate the accuracy of the satellite-based surface temperature values. These ground-based measurements themselves had a variance of about 6 ($C^2$), due to the high variability of surface temperature at their very micro-scale (1 m), even though the land-cover was uniform (prairie grassland). Emissivity correction was

performed by assignment of a single value for the entire land surface. The atmospheric modeling methods were found to produce acceptable surface temperature accuracies (to nearest 3 C); all but one of the split-window techniques produced unacceptable surface temperature accuracies. This study indicated the difficulties associated with non-GIS manipulation of remote sensing data, as well as the fundamental unsuitability of ground-based point measurements of land-surface temperature as a basis for evaluating satellite-based meso-scale average land-surface temperature.

Henry et al. (1989). Henry et al. (1989) used NASA HCMM satellite thermal-infrared images in a meso-scale, GIS-based study of the urban heat-island effect of Gainesville, Florida. Detailed land-cover information corresponding to the United States Geological Survey (USGS) classification system (Anderson et al., 1976) came from maps and aerial photographs. Geographic correction was performed based on ground control points and a first-order polynomial surface model; registration accuracy was estimated solely by the root-mean-square (rms) error of the fitted points (± 0.6 pixel). Atmospheric correction was performed by the atmospheric modeling method, with radiosonde data. Emissivity correction was performed by assignment of a single value for all urban/suburban land-cover. Quality evaluation was very limited--based on near-surface air temperature measurements collected non-simultaneously (different year) from the satellite data; the authors acknowledged that even

simultaneous measurements of surface and near-surface air temperature could vary on the order of 10 C. Despite this problem, general heat-island impact differences were noted for several urban and rural land-cover types through GIS-based analyses. This study showed the power of GIS as an analytical tool for linking satellite image data and map data, the value of geographic registration accuracy evaluation, the necessity of temperature accuracy evaluation, and the unsuitability of using near-surface air temperature to evaluate surface temperature accuracy.

Luvall et al. (1990). Luvall et al. (1990) used airborne thermal-infrared sensor images in a micro-scale study of Costa Rican rainforest canopy temperature and ET. Atmospheric correction was performed by the atmospheric modeling method, with radiosonde data. No emissivity correction was reported, but the surface-temperature study was limited to full-canopy vegetation surfaces having emissivity near unity. Lack of both geographic correction and GIS capability led to eyeball estimates of image subsets corresponding to polygons on aerial photographs. Verification data in the form of thermocouple leaf-temperature measurements at the top of the canopy indicated an average remotely-sensed surface temperature accuracy to the nearest 1.1 C. This study indicated the potential for remote measurement of surface temperature over forest canopy, the suitability of vegetation surface temperature measurements for evaluating the accuracy of remotely-sensed vegetation surface temperature, the need for

GIS-based analysis, and the need for geographic registration and accuracy assessment.

Sucksdorff and Ottlé (1990). Sucksdorff and Ottlé (1990) used NOAA TIROS AVHRR thermal-infrared images in a meso-scale study of ET in Finland. Geographic correction was performed by registration to a base map. Atmospheric correction was performed by the atmospheric modeling technique, using radiosonde data. No accuracy evaluation was reported for the geographic correction or the temperature data. This study demonstrated the use of base-map image registration to construct a raster GIS database, as well as the need for evaluation of geographic and temperature accuracy.

Leshkevich et al. (1993). Leshkevich et al. (1993) used NOAA TIROS AVHRR images to construct an archive of quality-assurred Great Lakes water-surface images. Geographic correction was performed based on satellite orbital telemetry data; manual offsets of up to 10 km were required for image registration to allow construction of a raster GIS. No further evaluation of geographic accuracy was reported. Atmospheric correction was performed by a split-window technique. Lake surface temperatures (day and night) were determined to be accurate to the nearest 1 C, based on comparisons with near-surface water-body temperature verification data. This study illustrated the value of GIS as an analytical tool, and the suitability of water-body temperature measurements in accuracy assessment of remotely sensed water surface temperature values.

Gillies and Carlson (1994). Gillies and Carlson (1994) used NOAA TIROS AVHRR images in a study to estimate meso-scale surface moisture-availability (ratio of soil moisture content to that at field capacity) in northeast England. Four afternoon spring and summer images from 1989 to 1990 were calibrated to at-satellite radiant temperature. Atmospheric correction was performed by the atmospheric modeling method, using radiosonde data. No emissivity correction was reported. Geographic correction was performed based on ground control points, and the positional accuracy was determined to be acceptable (0.8 km maximum rms error). Moisture-availability estimation was evaluated based on point measured data, and was found to be accurate to the nearest 5 to 7%. This study indicated the potential for quantitative analyses of surface parameters obtained from satellite images, and the increased geographic accuracy resulting from the use of ground control points, rather than relying solely on satellite orbital telemetry for image geographic registration.

Current directions in land surface temperature research. A methodology for detailed, meso-scale, quantitative study of land-surface temperature patterns involving a GIS containing the full set of forcing factors has been called for by several researchers (Taconet et al., 1986a; Henderson-Sellers and McGuffie, 1987; Dickinson, 1988; MacCracken et al., 1990; Lagouarde, 1991; Mather and Sdasyuk, 1991; Sobrino et al., 1991; Dozier, 1992; Kerr et al., 1992; Brown et al., 1993; Lindsey et al., 1993; Wheeler, 1993). This methodology would

necessarily involve careful attention to the matters of atmospheric correction, emissivity correction, geographic correction, and quality analysis of both temperature and pixel registration (Henderson-Sellers and Robinson, 1986; Harries, 1990; Mather and Sdasyuk, 1991; Peters et al., 1992). These recommendations were put forth in simplest form by Heimburg et al. (1982, p. 128):

> An estimation procedure can be no more accurate than allowed by its weakest part. From this perspective, the most important area for future research is development of operational methods to determine surface temperature and net radiation from satellite data. This development includes solutions to the problems of image registration and atmospheric absorption corrections. The ability to accurately overlay visible and [thermal] infrared data collected at different times from the same area on the earth's surface is critical to all remote-sensing methods [for evapotranspiration estimation], as is the ability to correct temperature and net radiation estimates for atmospheric effects.

Satellite data suitable for such work now exist (Sader et al., 1990; NOAA, 1991; Di and Rundquist, 1994; Gillies and Carlson, 1994), as do geographic information systems for performing sophisticated analyses (ESRI, 1990; Lo and Shipman, 1990; Tan and Shih, 1990; ERDAS, 1991; Wood, 1991; Rutchey and Vilcheck, 1994; Srinivasan and Engel, 1994; Wong, 1994).

## MATERIALS AND METHODS

This research was performed on hardware consisting of a personal computer (PC), high-resolution monitor, and digitizing tablet. Software used included the PC versions of the Earth Resources Laboratory Application Software (ELAS), Earth Resources Data Acquisition System (ERDAS), and ARC/INFO. The ground-based DSTV/soil-moisture work utilized soil augers, hand-held radiometer, thermistors, and the gravimetric soil-moisture analysis equipment of the University of Florida Soil and Water Science Department.

### Study Area

The Florida study area is shown in Figure 1. There are three macroclimate zones--panhandle, north, and south (Fernald and Patton, 1984; Schmidt, 1992).

#### Panhandle Zone

The panhandle zone includes the Florida Panhandle, which for the purpose of this study is defined as the region to the west of the St. Marks river. Its macroclimate is warm-temperate, with a relatively wet winter (Fernald and Patton, 1984). Vegetation is limited to warm-temperate species (Clewell, 1985). The natural forest trees include evergreen broadleaf types and palms, as well as deciduous broadleaf

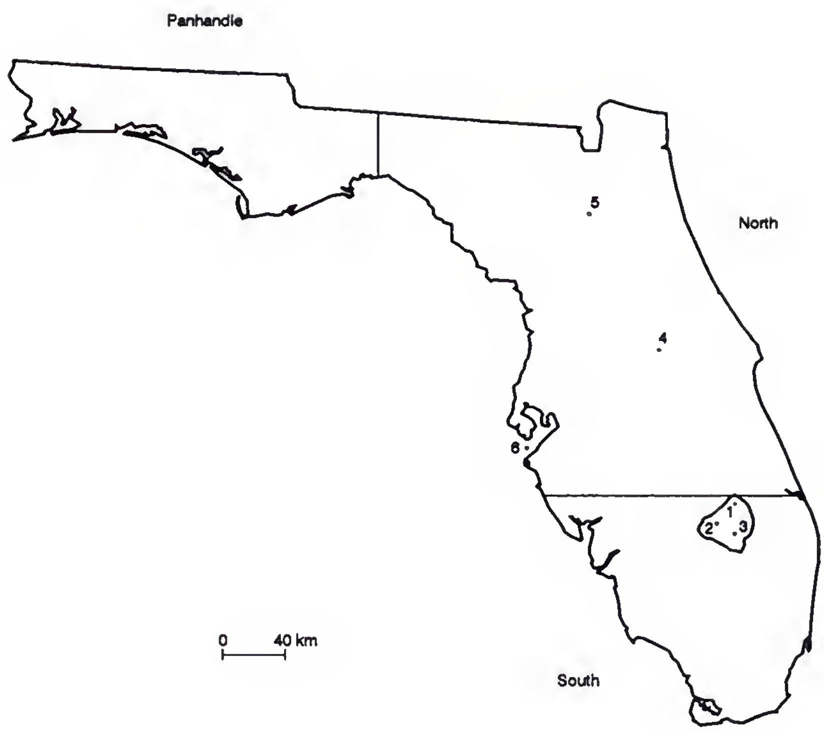


Figure 1. Study area with climate zones and water-body temperature stations (see Appendix B for details).

types and both evergreen and deciduous conifers. The agricultural vegetation types include deciduous orchards and nearly year-round pasture and crops.

North Zone

The north zone, for the purpose of this study, includes the region to the east of the St. Marks river and to the north of Lake Okeechobee. It is a transition zone, with a macroclimate that is warm-temperate to sub-tropical, with a winter that is relatively drier than that of the panhandle, but not as dry as that of the south (Fernald and Patton, 1984; Schmidt, 1992). Vegetation is limited to warm-temperate and sub-tropical species. The natural forest trees include evergreen broadleaf types and palms, as well as deciduous broadleaf types and both evergreen and deciduous conifers. The agricultural vegetation types include both evergreen and deciduous orchards, and nearly year-round pasture and crops.

South Zone

The south zone, for the purpose of this study, includes the region from Lake Okeechobee southwards. Its macroclimate is sub-tropical, with a distinctly dry winter (Fernald and Patton, 1984; Schmidt, 1992). Vegetation includes warm-temperate, sub-tropical, and tropical species (Barrett, 1956; Elias, 1980; Morton, 1982; FDNR, 1990). The natural forest trees include evergreen broadleaf types and palms, deciduous broadleaf types (some tropical), and both evergreen and

deciduous conifers. The agricultural vegetation types include both evergreen and deciduous (some tropical) orchards, year-round pasture and crops, and multi-season field crops.

## Geographic Information System

The GIS database used in this research was assembled from both raster and vector components, or "layers". The raster layers included satellite images; the vector layers included land-cover and soil type data.

### Raster Datasets

A raster dataset consists of lines and elements ("rows" and "columns"). The number of elements per line is a constant, forming in concept a rectangular grid, each identically-sized unit (picture element or "pixel") of which is assigned data in the form of digital numbers (DNs). There is one DN for each data type (sensor band, etc.) included in the raster. ELAS and ERDAS were used to store and manipulate the image raster files. Further information about raster datasets can be found in ERDAS (1991).

### Vector Datasets

A vector dataset consists of nodes and arcs which make up individual polygons. One or more polygons may be included within a "coverage" of a particular geographic region. For example, a pasture-on-muck-soil coverage might consist of several individual polygons distributed across Florida. Each

polygon can be assigned an attribute file, which contains one or more types of data (such as ownership, water-quality parameters, etc.). In this research, attribute files were not constructed for the polygons, since the polygons were intended for importation into the raster environment. ARC/INFO (modules "ADS", "CREATE", and "TABLES") was used to record the digitized map polygons as vector files. Further information about vector datasets can be found in ESRI (1990).

Geographic Referencing

Both raster and vector datasets must be geographically referenced in order to be included in a GIS (ESRI, 1990; Connin, 1994; Wong, 1994). Raster datasets are geographically referenced by knowledge of pixel size and the position (measured either from pixel center or a pixel corner) of one raster-corner pixel (typically the upper-left). Vector datasets are geographically referenced by knowledge of the position of each node. A consistent geographic coordinate system must be used for all of the datasets in the GIS. The Universal Transverse Mercator (UTM) system was selected for use throughout this study. It is commonly used on maps having conformal projection (suitable for navigation) published by the United States Geological Survey (USGS) and other agencies. Further information about geographic referencing and map projections can be found in ERDAS (1990).

GIS Analyses in Raster Environment

Analyses in this study were performed in a raster environment. Polygon files in ARC/INFO vector format were converted to ERDAS raster format ("DIG" file) equivalents. This conversion was performed using ARC/INFO modules "TRANSFORM" and "UUNGEN", and ERDAS module "DXIN". Statistical data (mean and standard deviation) were then extracted from the raster data (temperature values) corresponding to each polygon. This extraction process was performed using the ERDAS modules "CUTTER", "STITCH" (for assembling coverages of more than one polygon), and "BSTATS". Where a given land-cover polygon contained more than one soil type, it was subdivided (using ERDAS module "DIGSCRN") into two or more final polygons having a single land-cover and a single soil type.

Analyses of surface temperature patterns were performed using the mean, standard deviation, and sample-size data extracted from the GIS. Separate within-zone analyses were performed for the three macroclimate zones. T-tests were run at $\alpha$ = 0.05 and $\alpha$ = 0.01. The test statistic was given by the separate-variance formula (Ott, 1988):

$$T = \frac{\underline{x}_1 - \underline{x}_2}{(s_1^2/n_1 + s_2^2/n_2)^{0.5}} \qquad [15]$$

where $\underline{x}_1$ and $\underline{x}_2$ are the respective means of samples 1 and 2, $s_1$ and $s_2$ are the respective standard deviations of samples 1

and 2, and $n_1$ and $n_2$ are the respective sample sizes of samples 1 and 2. The difference of two sample means was considered statistically significant if $T < -t_{\alpha/2}$ or $T > t_{\alpha/2}$. In the analyses reported in this study, $n_1 + n_2 >> 30$, so that the critical values were $t_{0.025} = 1.960$ and $t_{0.005} = 2.576$ (Walpole and Myers, 1978).

## AVHRR Image Processing

NOAA TIROS-AVHRR images of surface temperature were obtained for two seasons and two times-of-day. Two day/night pairs of images (14 December 1989 and 12 December 1992) were required for complete winter coverage of Florida, due to partial cloud contamination. A single day/night pair of images (11 April 1993) was adequate for spring coverage of the state. Details of individual images are provided in Appendix A.

Winter (December) images allowed the analysis of differences in surface temperature patterns due to natural defoliation (for deciduous vegetation types) and agricultural management practices (winter-crop season). Deciduous vegetation in Florida includes both temperate and tropical species, so that seasonal effects could be studied in all three climate zones.

Spring (April) images allowed the analysis of differences in surface temperature patterns due to growth flush (for natural and many cultivated vegetation types) and agricultural

management practices (spring-crop season). It is a season of particularly high irrigation demand in agricultural and suburban areas in all three climate zones.

Time-of-day for the images included nighttime (late night/early morning) and daytime (afternoon). Repeat coverage of a given spot at nearly the same LST occurs every 9 days (Kerr et al., 1992) for TIROS satellites, so that a minor variation in coverage time occurs from day to day within this period. There are also long-term changes in repeat-coverage time for TIROS satellites; these are very gradual (years), compared to changes for other weather-satellites such as the Russian Meteor series (weeks). Nighttime (c. 0300 h LST), surface temperature images represented the minimum values in the diurnal cycle. Daytime (c. 1500 h LST) surface temperature images represented the maximum values in the diurnal cycle. The difference between these two values was the DSTV, which indicated relative values of daily-average root-zone soil moisture for a given land-cover/soil type combination.

<u>AVHRR Data Types</u>

The NOAA TIROS-satellite AVHRR images were obtained from the National Environmental Satellite Data and Information Service (NESDIS) in the form of local area coverage (LAC) level 1b packed format data on computer-compatible tapes (CCTs). Each tape was down-loaded, and then one raster file of image data, one tabular file of Earth Location Points

(ELPs), and one tabular file of calibration coefficients were extracted.

LAC-format AVHRR. AVHRR LAC images have the full spatial resolution (1.1 km nominal at nadir) of the AVHRR; the thermal-infrared bands have the full AVHRR radiometric precision of 0.1 C, stored in 10-bit (0-1024 DN) data precision (NOAA, 1991). The AVHRR bands are described (NOAA, 1988) as follows: band 1 (red) at 0.58 to 0.68 $\mu$m, band 2 (near-infrared) at 0.725 to 11.1 $\mu$m, band 3 (midwave thermal-infrared) at 3.55 to 3.93 $\mu$m, band 4 (longwave thermal-infrared) at 10.3 to 11.3 $\mu$m, and band 5 (longwave thermal-infrared) at 11.5 to 12.5 $\mu$m. For typical earth surfaces (not hot lava flows, fires, etc.), AVHRR bands 1 and 2 measure reflected energy (daytime only), band 3 measures both reflected (in daytime) and emitted energy, and bands 4 and 5 measure emitted energy (daytime or nighttime).

Other AVHRR formats. There are other forms of AVHRR image which do not retain full spatial resolution nor full radiometric precision, but are made available with greater frequency than LAC. For each TIROS satellite, a single 10-minute AVHRR High Resolution Picture Transmission (HRPT) image per 102-minute orbit can be stored on-board for later transmission to a NOAA ground reception station (NOAA, 1991), but there are usually only two orbital coverages of a given location per day, and not every transmitted HRPT image is selected for inclusion in the NOAA LAC archive. More frequent availability is provided by the NOAA-archived global area

coverage (GAC) format AVHRR images, which have reduced spatial resolution (4 km nominal at nadir), but keep the original data precision (10 bits); a complete orbital path of GAC data can be stored on-board per orbit for later transmission to a NOAA station (NOAA, 1991). Users with their own digital-signal ground station can receive HRPT images directly, and achieve a coverage frequency of at least twice per day from each operational satellite, but they also have to calculate their own ELPs and calibration coefficients from the HRPT telemetry (Brush, 1985; Emery et al., 1989; Klaes and Georg, 1992).

Users with their own analog-signal ground station can receive automatic picture transmission (APT) format AVHRR images, with reduced spatial resolution (4 km nominal at nadir) and reduced data precision (8 most significant bits pre-analog), and achieve a coverage frequency of at least twice per day from each operational satellite every day (NOAA, 1982b). APT images contain their own calibration information (NOAA, 1982b, 1988; Olivier, 1990), but have no ELPs nor the telemetry information to calculate them (NOAA, 1988). They are limited to two NOAA-selected AVHRR bands--typically bands 2 and 4 in daytime, and bands 3 and 4 at nighttime.

Use of TIROS/Meteor APT archive. During the course of this research, the APT ground station located at the Remote Sensing Application Laboratory (RSAL) of the University of Florida Agricultural Engineering Department was utilized to obtain APT images for purposes of building a browse file for selecting dates and times for ordering NOAA LAC images. These

APT images included multiple daily coverages by the four current NOAA TIROS satellites (NOAA-9, -10, -11, -12) and the short-lived but productive NOAA-13, and also the Meteor-APT of various Russian Meteor-series weather satellites (Meteor 2-21, 3-3, 3-4, and 3-5). The Meteor APT consists of daytime panchromatic (0.5 to 0.7 $\mu$m) images at somewhat finer spatial resolution (2 km nominal at nadir). It should be noted by users of weather-satellite data that imagery from the NOAA TIROS-series satellites (as well as the Russian Meteor-series satellites) is subject to temporary suspension on rare occasions due to participation in the international Search and Rescue Satellite (SARSAT) program in cases of emergencies at sea (WMO, 1989; NOAA, 1991).

## Calibration to At-Satellite Radiant Temperature

The thermal-infrared, 10-bit, image data of AVHRR bands 4 and 5 were calibrated to at-satellite radiant temperature by the method of NOAA (1991). One pair of calibration coefficients (scaled slope and intercept of the sensor internal calibration) was extracted from the level 1b LAC CCT for each scan line of the image. At-satellite radiant temperature was then calculated for the pixels of each line by the equation (NOAA, 1991):

$$T_{rad,sat,i} = \frac{C_2 \; CWN_i}{\ln \left[1 + C_1 \; CWN_i^3 \; / \; (S_i \; DN + I_i)\right]} \qquad [16]$$

where $T_{rad,sat,i}$ is the at-satellite radiant temperature (K) in

band $\underline{i}$, $C_1$ is a constant = 1.1910659x10$^{-5}$ (mW m$^{-2}$ ster$^{-1}$ cm$^4$), $C_2$ is a constant = 1.438833 (cm K), $CWN_i$ is the central wave number (cm$^{-1}$) for band $\underline{i}$ in one of three discrete target-temperature ranges, $S_i$ is the scaled calibration slope (mW m$^{-2}$ ster$^{-1}$ cm) for band $\underline{i}$, and $I_i$ is the scaled calibration intercept (mW m$^{-2}$ ster$^{-1}$ cm) for band $\underline{i}$, and DN is the 10-bit digital number (0 to 1023).

This calibration technique is based on a linear fit of AVHRR sensor response to target temperature within three discrete target-temperature ranges (180 to 225 K, 225-275 K, 275-320 K). It greatly reduces the at-satellite radiant temperature errors (up to 4.3 K at extremities) that would result from a simple two-point calibration over the entire target-temperature range (180 to 320 K) of AVHRR data (NOAA, 1988). It should be noted that a although a single target-temperature range (270-310 K) is generally employed in AVHRR calibration for sea-surface work (NOAA, 1991), all three standard target-temperature ranges have to be addressed in daytime land surface work. In addition, there is an upper limit of 320 K (47 C) for target temperature; the AVHRR longwave thermal-infrared band sensors saturate (DN = maximum) at this limit, and higher at-satellite radiant temperatures cannot be recorded (NOAA, 1988; Chuvieco and Martin, 1994). Fortunately, none of the images used in this study contained at-satellite radiant temperature data reaching this saturation limit.

Scaling of the output radiant temperature values was performed in order to retain as high a level of radiometric precision as possible (0.2 C) in the 8-bit (0 to 255 DN) data storage format to be used in the GIS of this research. The scaling was given by the equations:

$$DN_i = 5\ (T_{rad,sat,i} + 10) \qquad [17]$$

and

$$DN_i = 6\ (T_{rad,sat,i} - 15) \qquad [18]$$

where $T_{rad,sat,i}$ is the at-satellite radiant temperature (C) in band _i_, and $DN_i$ is the 8-bit scaled digital number output for band _i_. Equation 17 was used for nighttime and winter afternoon images; equation 18 was used for spring afternoon images.

## Geographic Correction and Registration

A base-map image was constructed to allow registration of the AVHRR images prior to their importation into the GIS. Weather-satellite images without any geographic correction are completely unusable in a GIS (Figure 2). Base-map construction, and subsequent AVHRR image registration, was performed using a two-stage geographic correction process, as is recommended (Thomas et al., 1987; Chen and Lee, 1992; Peters et al., 1992) for highly warped (containing distortions requiring a second-order or higher global polynomial surface model) imagery.

Figure 2. AVHRR image without geographic correction (polygon outlines true position of Florida).

The first stage involved the use of the extracted ELP data from the AVHRR LAC image. These ELPs, which are provided in the form of latitude/longitude coordinates, are imbedded in the raw image at every 40th pixel along each scan line. They form an evenly-distributed network of known geographic coordinates throughout the entire image, which is the most desirable situation for application of geographic correction techniques. The accuracy of these coordinates is dependent upon the accuracy of the satellite orbital telemetry data used by NOAA to calculate them (NOAA, 1991). Early in the course of this study, it was found that geographic correction based solely on the ELPs produced output images with positional errors of up to 10 km (Figure 3); this problem has been reported in several AVHRR-based studies (Cornillon et al., 1987; Nelson, 1989; Leshkevich et al., 1993). It should be noted that the positional error shown in Figure 3 is not a simple offset; there are still second-order distortions present in the image.

In order to keep output positional errors closer to the nominal spatial resolution (1.1 km) of the raw AVHRR LAC images, a second stage of refined geographic correction was performed based on ground control points (GCPs). The picking of these GCPs simultaneously from monitor displays of the AVHRR image (band 2 in daytime, band 4 at night) and from maps was greatly facilitated by the first stage of correction, which had removed most of the Earth-curvature and view-angle distortions. Picking of GCPs directly from the raw image is

Figure 3. AVHRR image with first-stage (ELP-based) geographic correction (polygon outlines true position of Florida).

not advisable, since the application of the high-order global polynomial surface model required for such a distorted image, combined with the relatively poor distribution of GCP network obtainable from most images, can easily result in instability of pixel fits interpolated between the GCPs (Thomas et al., 1987), and "explosion" of pixel fits extrapolated outside of the GCP network (Figure 4).

First-stage geographic correction of base-map image. First-stage geographic correction was performed using the ELP data extracted from the raw AVHRR LAC image. These ELP data formed a 240-ELP grid (consisting of 16 grid lines with 15 ELPs each) having a 40 x 40 pixel spacing. The latitude/longitude values in this ELP grid were converted to Universal Transverse Mercator (UTM) northing/easting values (UTM zone 17 format) and entered into the ERDAS module "GCP". A second-order global polynomial surface model was fitted to the ELPs. The Nearest-Neighbor resampling technique was then applied to the image; this is the only resampling technique that does not corrupt (smooth or average) image data values (Lillesand and Kiefer, 1979; Peters et al., 1992). These two operations were performed using ERDAS modules "COORDN" and "NRECTIFY." The polynomial fit (mapping equation) was as follows:

$$E' = 1000\ a_0 + a_1\ E + a_2\ L + 0.001\ a_3\ E^2 + 0.001\ a_4\ E\ L + 0.001\ a_5\ L^2$$

and

$$L' = 1000\ b_0 + b_1\ E + b_2\ L + 0.001\ b_3\ E^2 + 0.001\ b_4\ E\ L + 0.001\ b_5\ L^2 \qquad [19]$$

Figure 4. Example of explosive extrapolation of third-order global polynomial surface model outside of control points.

where E was the original element number, L was the original line number, $E'$ was the fitted element number, $L'$ was the fitted line number, and the values of the coefficients were $a_0$ = 1.371406, $a_1$ = -0.1608168E-2, $a_2$ = -0.3716236E-3, $a_3$ = 0.4853050E-6, $a_4$ = 0.1728803E-6, $a_5$ = 0.2920270E-7, $b_0$ = -2.333373, $b_1$ = -0.1690915E-3, $b_2$ = 0.8806317E-3, $b_3$ = -0.2704551E-8, $b_4$ = 0.2105952E-7, and $b_5$ = 0.3205131E-8, which are unitless. Resampling was done to an output pixel size of 1 km. Details concerning geographic correction techniques for satellite images can be found in remote sensing literature (Lillesand and Kiefer, 1979; Gonzalez and Wintz, 1987; Thomas et al., 1987; ERDAS, 1990; Novak, 1992; Peters et al., 1992; Di and Rundquist, 1994).

<u>Second-stage geographic correction of base-map image</u>. The first-stage output image was then imported into ELAS. A set of 115 well-distributed GCPs (coastal features and lakes of size appropriate to the spatial resolution of the image) was picked simultaneously from a monitor display of the image and from 1:500,000 scale UTM maps of Florida (DMAAC, 1987). ELAS module "CPPP" and a digitizing tablet were the tools used for this process. Panhandle GCP coordinates, located within UTM zone 16, were converted to their equivalents in UTM zone 17 format. The first-stage output image was then re-imported into ERDAS along with the GCP set mentioned above. A second-order global polynomial surface model was fitted to the GCPs. The Nearest-Neighbor resampling technique was then applied to

the raster. The polynomial fit (mapping equation) was as follows:

$$E' = 1000\ a_0 + a_1\ E + a_2\ L + 0.001\ a_3\ E^2 + 0.001\ a_4\ E\ L + 0.001\ a_5\ L^2$$

and

$$L' = 1000\ b_0 + b_1\ E + b_2\ L + 0.001\ b_3\ E^2 + 0.001\ b_4\ E\ L + 0.001\ b_5\ L^2 \qquad [20]$$

where E was the original element number, L was the original line number, $E'$ was the fitted element number, $L'$ was the fitted line number, and the values of the coefficients were $a_0$ = 0.1952093, $a_1$ = 0.9931500E-3, $a_2$ = -0.3316682E-5, $a_3$ = 0.1140539E-7, $a_4$ = 0.3552246E-8, $a_5$ = 0.8012727E-9, $b_0$ = 3.655660, $b_1$ = -0.5229729E-4, $b_2$ = -0.1038144E-2, $b_3$ = 0.1049909E-7, $b_4$ = 0.1479114E-7, and $b_5$ = 0.5142951E-8, which are unitless. Second-stage resampling was done to an output pixel size of 1 km, to form a base-map image of 1000 elements by 1000 lines covering the entire Florida study area and small portions of southern Alabama and Georgia (Figure 5). Location of the first pixel (element 1, line 1) was at -187,000 m east and 3,584,000 m north (UTM zone 17 format) in the ERDAS raster GIS reference system.

Accuracy assessment of base-map image. The positional accuracy of the base-map image was carefully evaluated, since all future images would be registered to it. ERDAS module "COORDN" reported that the root-mean-square (rms) error for

Figure 5. AVHRR image with second-stage (GCP-based) geographic correction (polygon outlines true position of Florida).

the second-stage fit in the element direction was 0.648 km, and in the line direction was 0.597 km; the overall rms error for the fit was 0.881 km. These figures apply only to the GCP pixels, not to other resampled pixels; they represent a form of validation check. The potential for the user to be misled by these GCP-based rms values can be seen in the extrapolation-exploded image of Figure 4, which had a GCP-based rms error of only 1.2 km, even though the image was clearly rendered useless. In order to verify the positional accuracy of the entire base-map image, a set of 91 well-distributed GCPs (different from the 115 used to build the base-map image) were digitized in the manner described above. The resulting rms error was found to be 0.495 km in the element direction, and 0.566 km in the line direction; the overall rms error was 0.752 km. Considering both the overall rms error of the fit (0.881 km) and that of the verification (0.752 km), the base map was demonstrated to be spatially accurate to within 1 km.

Registration of subsequent images to base-map image. Subsequent AVHRR LAC images were registered to the base-map image by a two-stage process with ELP-based first-stage geographic correction similar to that described above. The only change was in the manner of picking the GCPs for the second-stage geographic correction; they were picked from simultaneous monitor displays of the first-stage corrected image and the base-map image (rather than maps). The ELAS module "OCON" was used to simultaneously display these images

and pick the GCPs. These GCPs and the AVHRR LAC image being registered were then imported into ERDAS for the second-stage geographic correction. Second-order global polynomial surface models were used whenever possible, but third-order models were used if second-order models were insufficient to produce registration rms errors below 1.2 km. Registered AVHRR images had rms errors ranging from 1.09 to 1.2 km. Registration details of individual images are given in Table 140 of Appendix A.

## Conversion from Radiant to Kinetic Temperature

In order to produce kinetic surface temperature images from the at-satellite radiant temperature images, a three-stage process was implemented. First, atmospheric correction of an at-satellite radiant temperature image (Figure 6) was performed by the water-body calibration technique. Second, an instantaneous pixel-average emissivity image (Figure 7) was constructed by the twin-band method. Third, the atmospheric-corrected radiant temperature image and emissivity image were used to produce a kinetic temperature image (Figure 8) based on the analytical solution of the Planck equation. The overall conservative bias due to the atmospheric effect, and the "hiding away" of high surface temperature in urban and agricultural areas due to the emissivity effect, are both evident in the uncorrected image of Figure 6, when it is compared to the fully corrected image of Figure 8.


Figure 6. At-satellite radiant temperature image.

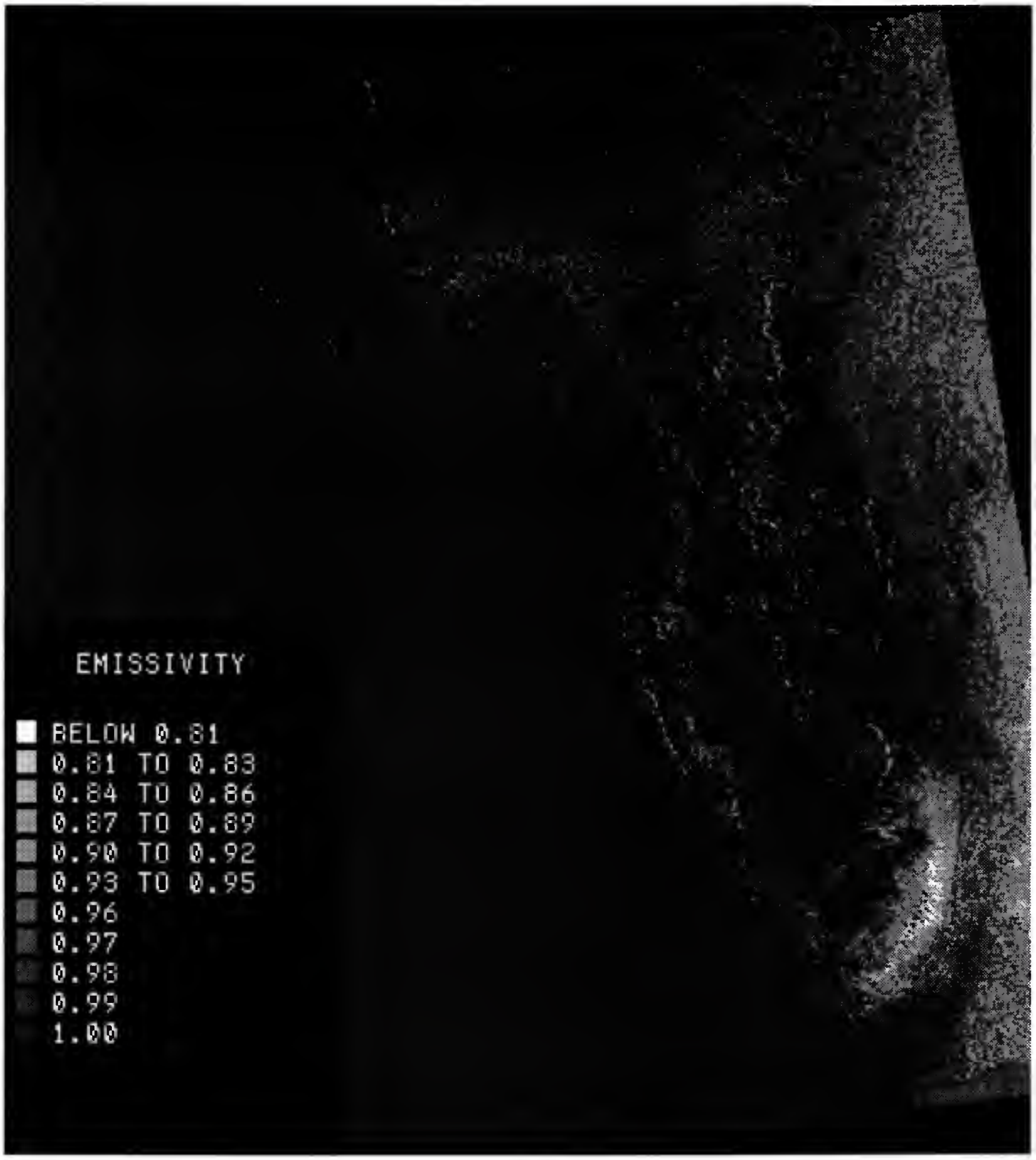


Figure 7. Emissivity image.

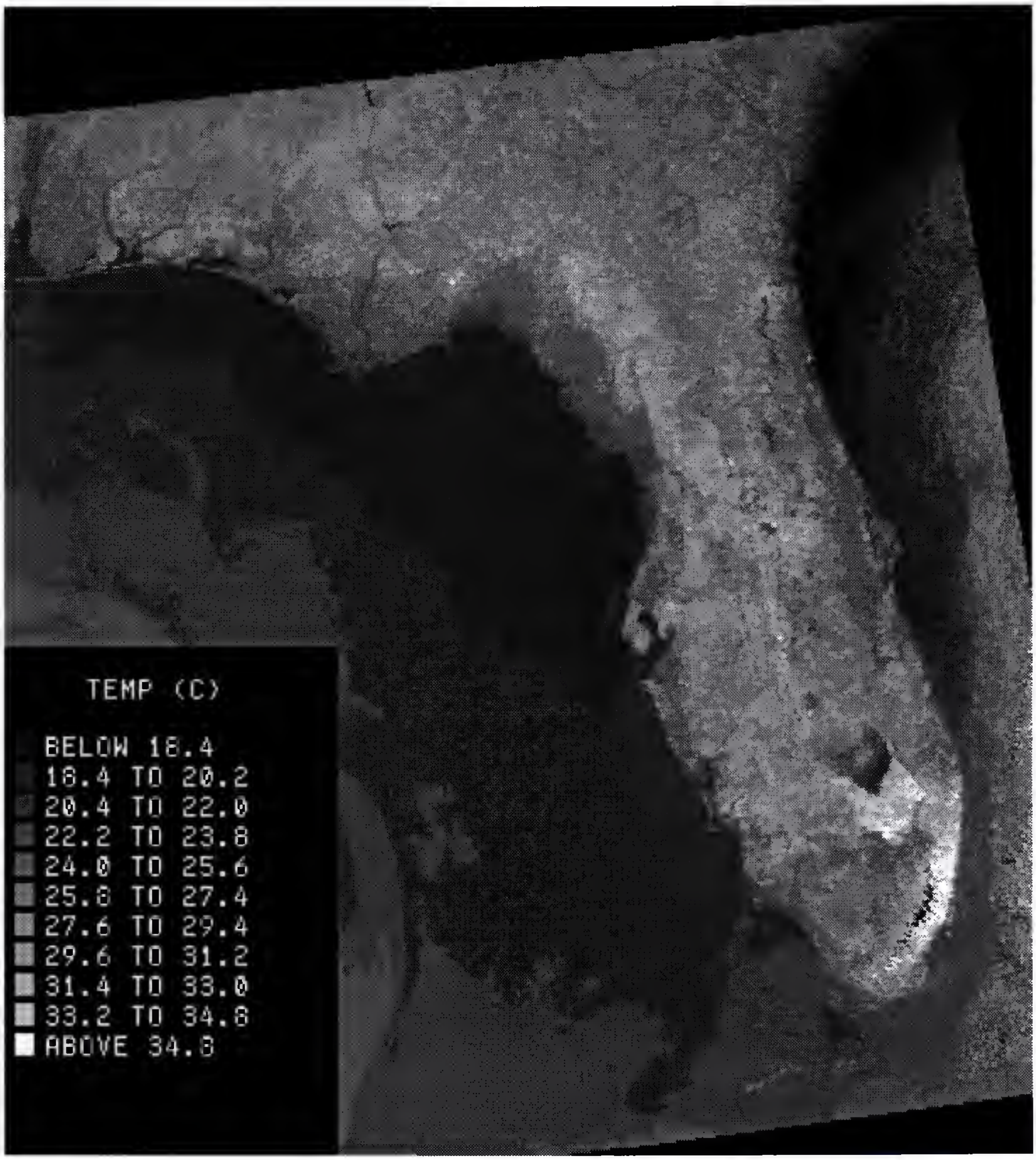


Figure 8. Surface temperature image.

Atmospheric correction. The water-body calibration technique described by Lillesand and Kiefer (1979) was performed on the at-satellite radiant temperature images from bands 4 and 5. This technique is based on the near-uniform emissivity and relatively stable temperature (over the satellite overpass time) of water-body pixels. Hourly near-surface (0.5 m) water temperature data from three permanent instrument stations located within Lake Okeechobee were obtained from the South Florida Water Management District (SFWMD) "DBHYDRO" database (Figure 1). These kinetic temperatures (thermistor-based values reported to nearest 0.1 C) were converted to AVHRR band 4 and 5 radiant temperature equivalents by rearranging equation 13 and plugging in the water temperatures:

$$T_{rad,i} = \frac{k\ CWN_i}{\ln\ \{\epsilon_w^{-1}\ [\exp\ (k\ CWN_i\ /\ T_{kin})\ +\ \epsilon_w\ -\ 1]\}} \qquad [21]$$

where $T_{rad,i}$ is the radiant temperature (K) calculated in band $\underline{i}$ for a station pixel, $T_{kin}$ is the measured water-surface kinetic temperature (K), $\underline{k}$ is the Boltzmann constant (1.438883 cm K), $CWN_i$ is the central wave number for band $\underline{i}$ ($cm^{-1}$), and $\epsilon_w$ is the longwave emissivity of the lake water. A well-established value of 0.99 was used for $\epsilon_w$ (Buettner and Kern, 1965; Barton and Takashima, 1986; Saunders, 1986; Masuda et al., 1988; Wukelic et al., 1989; Salisbury and D'Aria, 1992). Central wave numbers were obtained from the tabular values

published by NOAA (1991) for each TIROS satellite AVHRR sensor, each band $\underline{i}$, and each surface-temperature range. The highest surface-temperature range was used to find the $CWN_i$ for afternoon LAC images, and the sea-surface range was used to find the $CWN_i$ for nighttime and early-morning images. The differences between the at-satellite radiant temperatures and the atmospherically-corrected radiant temperatures were averaged (from up to 3 values, according to station data availability) to obtain atmospheric correction factors which were applied to the at-satellite radiant temperature data from bands 4 and 5 of each LAC image.

Emissivity correction. The atmospheric-corrected radiant temperature images from bands 4 and 5 were used to produce a longwave thermal-infrared emissivity image for each AVHRR image by the twin-band technique of Artis and Carnahan (1982). Instantaneous pixel-average emissivity calculation was performed by plugging appropriate AVHRR values into equation 14:

$$\epsilon_{lw} = \exp \{k \ (T_{rad,5}-T_{rad,4}) \ / \ [T_{rad,5} \ T_{rad,4} \ (\lambda_5-\lambda_4)]\} \qquad [22]$$

where $\epsilon_{lw}$ is the pixel-average longwave thermal-infrared emissivity, $\underline{k}$ is the Boltzmann constant (1.43883 cm K), $T_{rad,4}$ is the atmospheric-corrected band 4 radiant temperature (K), $T_{rad,5}$ is the atmospheric-corrected band 5 radiant temperature (K), and $\lambda_4$ and $\lambda_5$ are the respective central wavelengths (inverse of central wavelength number, m) of AVHRR bands 4 and

5. The last two values come from NOAA (1991) look-up tables for the TIROS satellite, band, and temperature range, as described previously. An 8-bit scaling of the calculated emissivity values preserved the precision to the nearest 0.01:

$$DN = 100\ \epsilon_{lw} \qquad [23]$$

where the parameters are described as before. The assumption in this method that surface emissivity values in AVHRR bands 4 and 5 are identical is a simplification (Price, 1984); slight differences in emissivity values between these bands (up to 0.01) will result in an uncertainty of 1 C when the calculated longwave-band emissivity is applied to kinetic temperature calculation.

<u>Kinetic temperature calculation</u>. The emissivity image was used with the atmospheric-corrected radiant temperature image from band 4 to calculate the kinetic temperature image for each AVHRR image. This computation was performed by plugging appropriate AVHRR band 4 values and the pixel-average emissivity values into equation 13:

$$T_{kin} = \frac{k\ CWN_4}{\ln\left[1 - \epsilon_{lw} + \epsilon_{lw} \exp\left(k\ CWN_4 / T_{rad,4}\right)\right]} \qquad [24]$$

where $T_{kin}$ is the pixel-average kinetic temperature (K); $T_{rad,4}$ is the atmosphere-corrected, pixel-average, band 4 radiant temperature (K); <u>k</u> is the Boltzmann constant (1.43883 cm K), $CWN_4$ is the central wave number for $band_4$ ($cm^{-1}$), and $\epsilon_{lw}$ is the pixel-average longwave emissivity. Band 4 central wave

numbers were obtained from the tabular values published by NOAA (1991) for each TIROS AVHRR sensor and each surface-temperature range. The highest surface-temperature range was used to find the $CWN_4$ for afternoon LAC images, and the sea-surface range was used to find the $CWN_4$ for nighttime and early-morning images. Scaling of the output $T_{kin}$ images to an 8-bit format was performed using the formula

$$DN = \begin{cases} 5\,(T_{kin} + 10), & \text{for low } T_{kin} \text{ images} \\ 6\,(T_{kin} - 15), & \text{for high } T_{kin} \text{ images} \end{cases} \qquad [25]$$

where $T_{kin}$ is the kinetic temperature (C), low-temperature images were defined as those having a range of land surface temperatures between -10.0 and 41.0 C, and high-temperature images were defined as those having a range of land surface temperatures between 15.0 and 57.0 C. In either case, a precision of 0.2 C was kept by the scaling. It should be noted that the AVHRR sensor saturation limit of 47 C applies only to at-satellite radiant temperatures; a surface such as a cleared sandy field or an urban area can have an afternoon kinetic surface temperature well above 47 C and yet, due to emissivity and atmospheric effects, it can easily have an at-satellite radiant temperature under 47 C.

Accuracy Assessment of Kinetic Temperature Images

The water-body temperature data used to calculate the atmospheric correction served as a validation data set. The

water-body temperature data from other stations served as a verification data set. Procedures and results of validation and verification are described below.

Validation of kinetic temperature. Validation assessment was performed using the previously mentioned near-surface water temperature data from the three permanent instrument stations located within Lake Okeechobee (Figure 1). This was done by comparing the processed image kinetic temperature values with the corresponding water-body temperature data. Errors indicated by the validation data set for the AVHRR kinetic temperature images ranged from 0.0 to 1.1 C; the average error was 0.5 C. This range of single-pixel basis validation error for lake surface temperature values is even lower than expected from the uncertainty associated with the twin-band emissivity correction method, and indicates that the station water-temperature (thermistor-based) data were themselves very well calibrated. Validation details of individual images are given in Table 140 of Appendix A.

Verification of kinetic temperature. Verification assessment was performed using near-surface (0.5 m) water temperature data from the permanent instrument station located within Lake Apopka, and from periodic sampling by boat in Lake Sampson and Tampa Bay (Figure 1). The Lake Apopka data were obtained from the St. Johns River Water Management District (SJRWMD); the Lake Sampson data were obtained from the Suwannee River Water Management District (SRWMD); the Tampa Bay data were obtained from the Environmental Protection

Commission of Hillsborough County (EPCHC). The processed image kinetic temperature value for each of these verification sites was compared with the corresponding near-surface water temperature data (thermistor-based values reported to nearest 0.1 C). Errors indicated by the verification data set for the AVHRR kinetic temperature images ranged from 0.4 to 3.4 C; the average error was 1.9 C. This range of single-pixel basis verification error values for atmospheric-corrected lake-surface temperature is slightly higher than that (0.2 to 0.8 C) reported for atmospheric-corrected sea-surface temperature under ideal clear-sky conditions (Llewellyn-Jones et al., 1984), but far lower than would be the case (up to 20 C) without atmospheric correction. Because the verification stations are located in a different zone (north) from the validation stations (south), they provide for each image a conservative check on the error due to statewide spatial variation in the atmospheric correction factor. Verification details for individual images are given in Table 140 of Appendix A.

## Water and Cloud Masking

A masking procedure was used to exclude kilometer scale water bodies and clouds from the surface temperature analyses in this study. The mask was prepared from a normalized difference vegetation index (NDVI) image (Figure 9). While NDVI is commonly applied to vegetation vigor studies (Fischer, 1994; Teillet and Fedosejevs, 1994; Wade et al., 1994), it


Figure 9. Water/cloud mask (NDVI) image.

also distinguishes water and cloud surfaces (NOAA, 1990). The NDVI was calculated from bands 1 and 2 (red and near-infrared) of the AVHRR image (NOAA, 1990):

$$NDVI = \frac{NIR - R}{NIR + R} \qquad [26]$$

where NIR is the band 2 DN, and R is the band 1 DN. This NDVI was scaled for 8-bit storage according to the standard global vegetation index (GVI) procedure (NOAA, 1990):

$$NDVI_s = \begin{cases} 255, & \text{for NDVI} < -0.05 \\ 0, & \text{for NDVI} > 0.60 \\ 240-350(NDVI+0.05), & \text{otherwise} \end{cases} \qquad [27]$$

where $NDVI_s$ is the scaled NDVI. Values of $NDVI_s$ above 219 were found by inspection to indicate water and cloud surfaces. A separate NDVI image was prepared for each diurnal image pair, using the daytime image band 1 and 2 data. This accounted for any changes in kilometer-scale cloud or water body extent--such as drifting clouds and floods. Each pixel of a surface temperature image which corresponded with a water/cloud pixel was then assigned a value of zero, creating a masked surface temperature image (Figure 10). When each GIS coverage was later analyzed using the ERDAS module "BSTATS," the option to exclude zero values from statistical computations was selected.

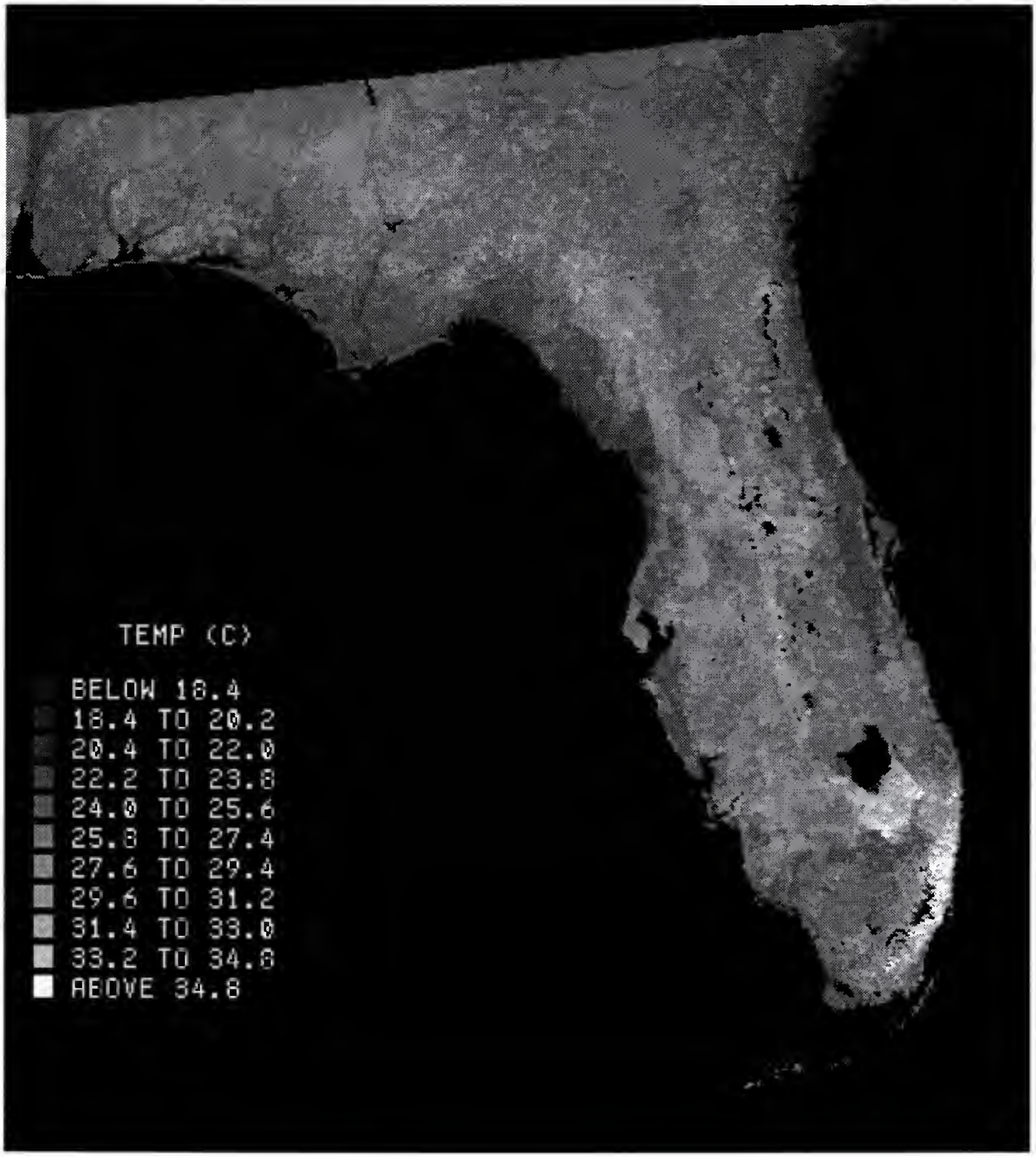


Figure 10. Daytime (spring) masked surface temperature image.

Final Forms of Images in the GIS Database

Examples of final-form masked daytime and nighttime surface temperature images are shown respectively in Figures 10 and 11. The nighttime image values were subtracted from the daytime image values using the capabilities of the GIS, producing a DSTV image (Figure 12).

## HCMM Historical-Image Processing

Analysis of historical temperature patterns was performed in order to supplement the previously described analysis of contemporary Florida temperature patterns. It was particularly desired to obtain meso-scale thermal-infrared images from a date preceding the freezes of the mid 1980s, which resulted in permanent changes in the citrus orchard component of agricultural land-cover. Although the NOAA-TIROS satellite series has been in operation since 1978, only 6% of the pre-1985 world-wide set of AVHRR-LAC images have been preserved (the reduced-resolution GAC was given priority for preservation) in the current NOAA archive (NOAA, 1991); the AVHRR-LAC archive extends only from 1985 to present. Therefore, the imagery used for historical analysis came from the short-lived NASA HCMM satellite program of 1979.

The NASA HCCM data were obtained from the National Space Science Data Center (NSSDC) in the form of CCTs. Each tape was down-loaded, and then one raster file of image data was extracted. These HCMM images had been calibrated and scaled


Figure 11. Nighttime (spring) masked surface temperature image.


Figure 12. DSTV (spring) image.

by NASA, and had a nominal at-nadir spatial resolution (in the thermal-infrared band) of 600 m. The radiometric precision of the HCMM longwave thermal-infrared band (10.5-12.5 $\mu$m) in the calibrated and scaled 8-bit form was 0.4 K (NASA, 1980). Because HCMM was designed for land-surface thermal imaging, rather than cloud-top/sea-surface work, its at-satellite radiant temperature sensitivity ranged from 260 to 340 K.

The orbit of the HCMM satellite was chosen so as to provide 12-hour repeat coverage for all of the globe, except for two narrow belts of latitude (15 to 35 degrees N and S) (NASA, 1980). Unfortunately, Florida lies within the northern 12-hour repeat-coverage exclusion belt, so that only one HCMM image per 24-hour period was possible. A set of relatively cloud-free HCMM images was selected which provided day/night repeat coverage of Florida within a 3-day period. These were dated 1 February 1979 (night) and 3 February 1979 (afternoon). Details concerning the HCMM images are provided in Appendix A.

Geographic Correction of HCMM Images

HCMM images from 12-hour repeat coverage areas were geographically corrected by NASA (NASA, 1980), but the HCMM images from the 12-hour exclusion belt were not. The HCMM images of Florida used in this study were geographically corrected using a single-stage (GCP-based) process similar to the second-stage (GCP-based) correction described previously for AVHRR images, since HCMM CCTs contain no ELP data. Registration to the previously described base-map image was

accomplished using 3rd-order global polynomial surface models and nearest-neighbor resampling to 500 m pixel size; rms errors were 1.19 km for both HCMM images. Each registered HCMM output consisted of an image of 2000 elements by 2000 lines covering the entire Florida study area and small portions of southern Alabama and Georgia. Location of the first pixel (element 1, line 1) was at -187,250 m east and 3,584,250 m north (UTM zone 17 format) in the ERDAS raster GIS reference system. Details of HCMM image geographic correction are given in Appendix A.

Calibration of HCMM At-Satellite Radiant Temperature

The HCMM image data were calibrated to at-satellite radiant temperature by the method of NASA (1980):

$$T_{rad,sat,h} = \frac{1251.1591}{\ln\left[14421.587 / (DN+118.21378) + 1\right]} \qquad [28]$$

where $T_{rad,sat,h}$ is the at-satellite radiant temperature (K) in the HCMM thermal-infrared band, and DN is the 8-bit digital number (0-255). It should be noted that the NASA-processed HCMM thermal-infrared data had already been radiometrically calibrated using a two-point (space and internal-target) technique with full non-linearity correction (NASA, 1980).

No atmospheric correction was performed on the HCMM images, due to lack of any existing water-body temperature stations at the time of the images. No emissivity correction was performed on the HCMM images for the same reason, plus the

fact that HCMM possessed only a single thermal-infrared band (which spanned the wavelength ranges of AVHRR bands 4 and 5). The afternoon and night HCMM images are shown in Figures 13 and 14.

An approximation of DSTV, shown in Figure 15, was calculated by subtraction of night HCMM temperatures from afternoon HCMM temperatures. It should be noted that this approximate-DSTV is not as rigorously defined as the DSTV from the AVHRR images, since the HCMM images were separated in time by more than 1 day, and no corrections for atmospheric or emissivity effects were made.

## Ground-Based DSTV/Soil-Moisture Work

Ground-based investigations of the DSTV/soil-moisture relation were conducted for the cases of mineral and organic soil types. The methodology of this work is described below.

### Mineral Soil Investigation

Mineral soil (Ellzey fine sand) effects on DSTV were investigated at the Hastings Agricultural Research and Education Center (AREC) located near Hastings, Florida. Soil type and drainage conditions of the experimental potato fields are typical of those found in the rest of the Hastings/Spuds/ Tocoi spodosol row-crop area (Appendix C, agricultural polygon number 38).

From 11 to 12 March 1991, five sites consisting of bare sand soil under the widest available variety of moisture

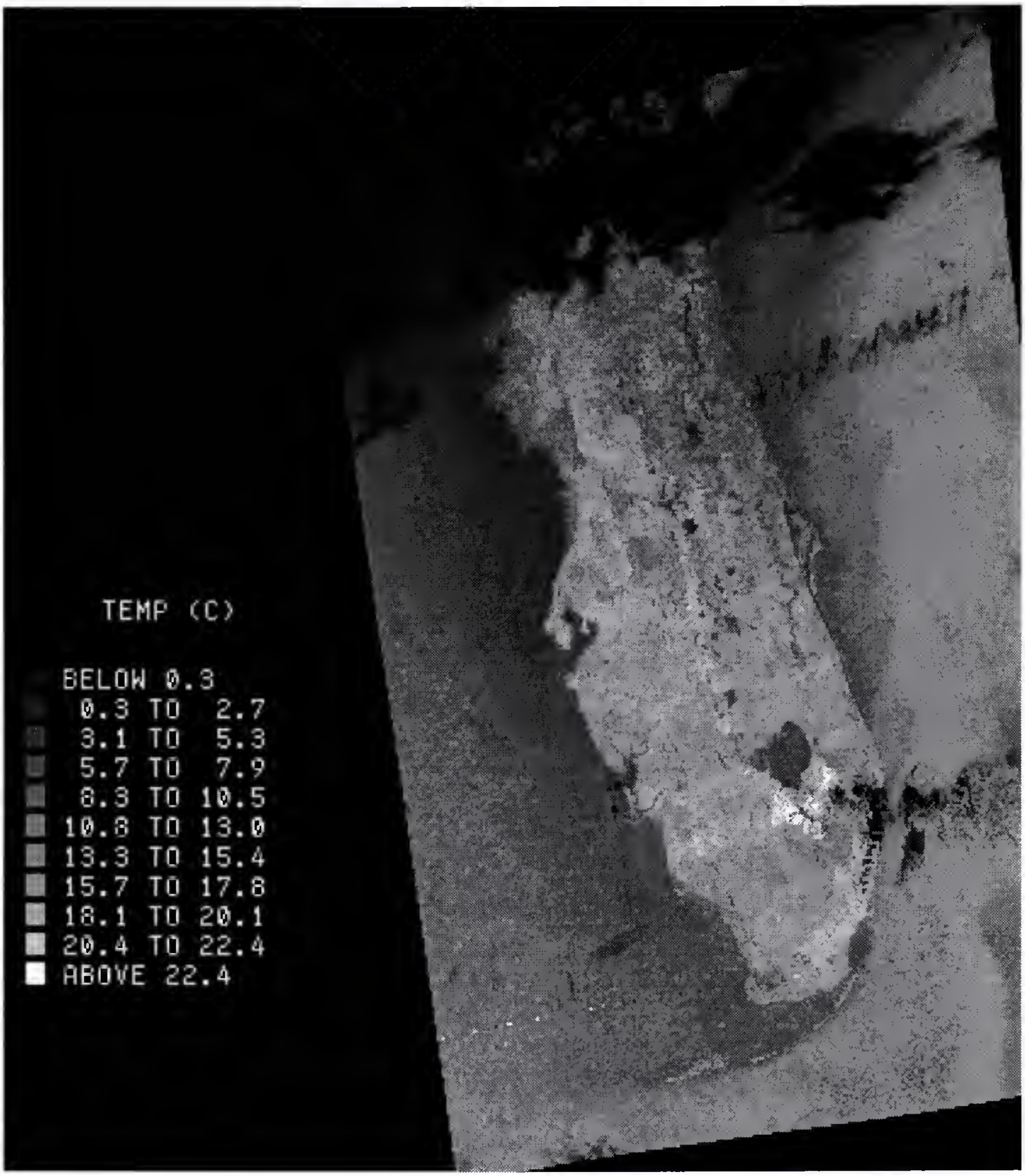


Figure 13. HCMM daytime (winter) at-satellite radiant temperature image.

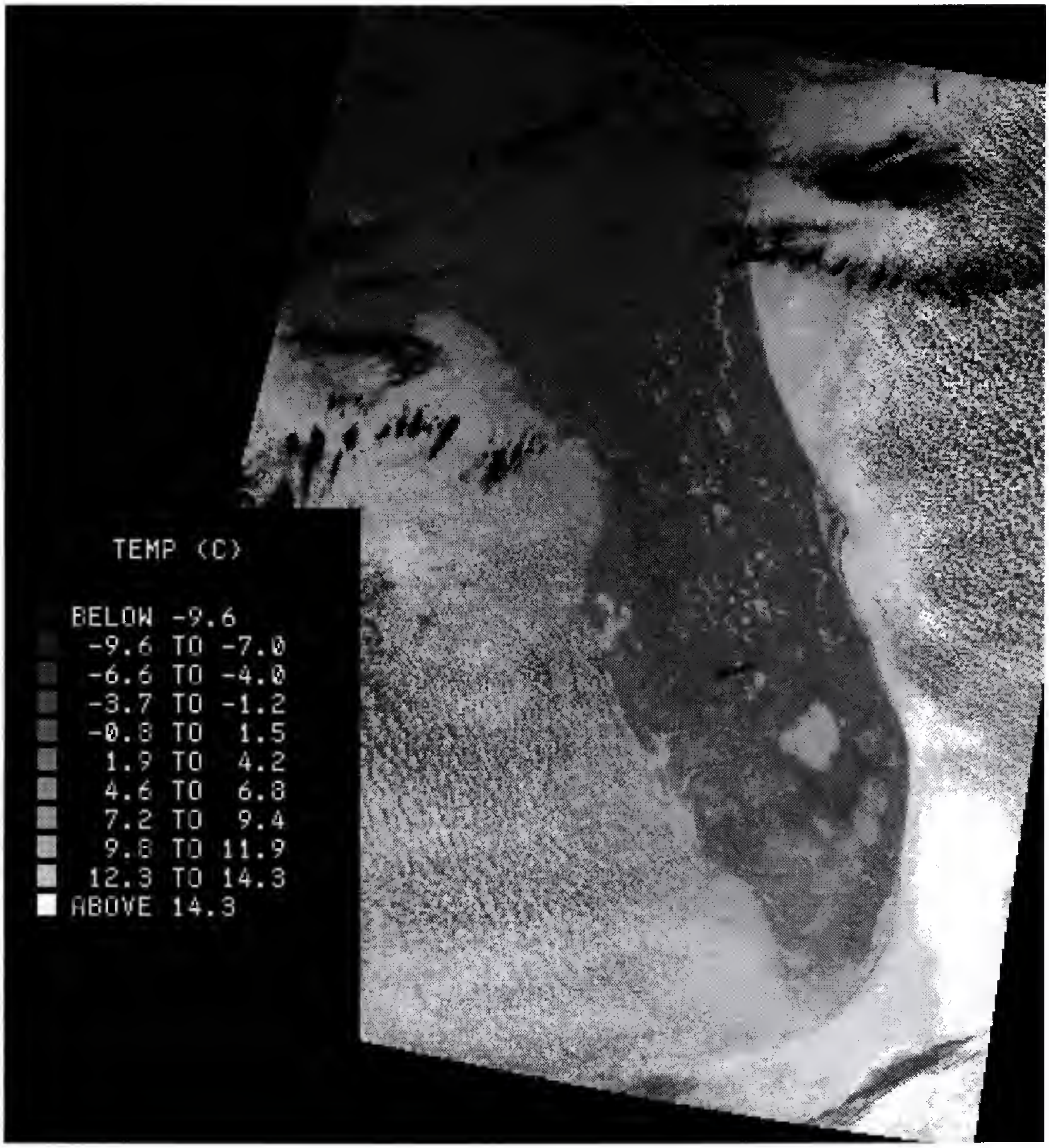


Figure 14. HCMM nighttime (winter) at-satellite radiant temperature image.

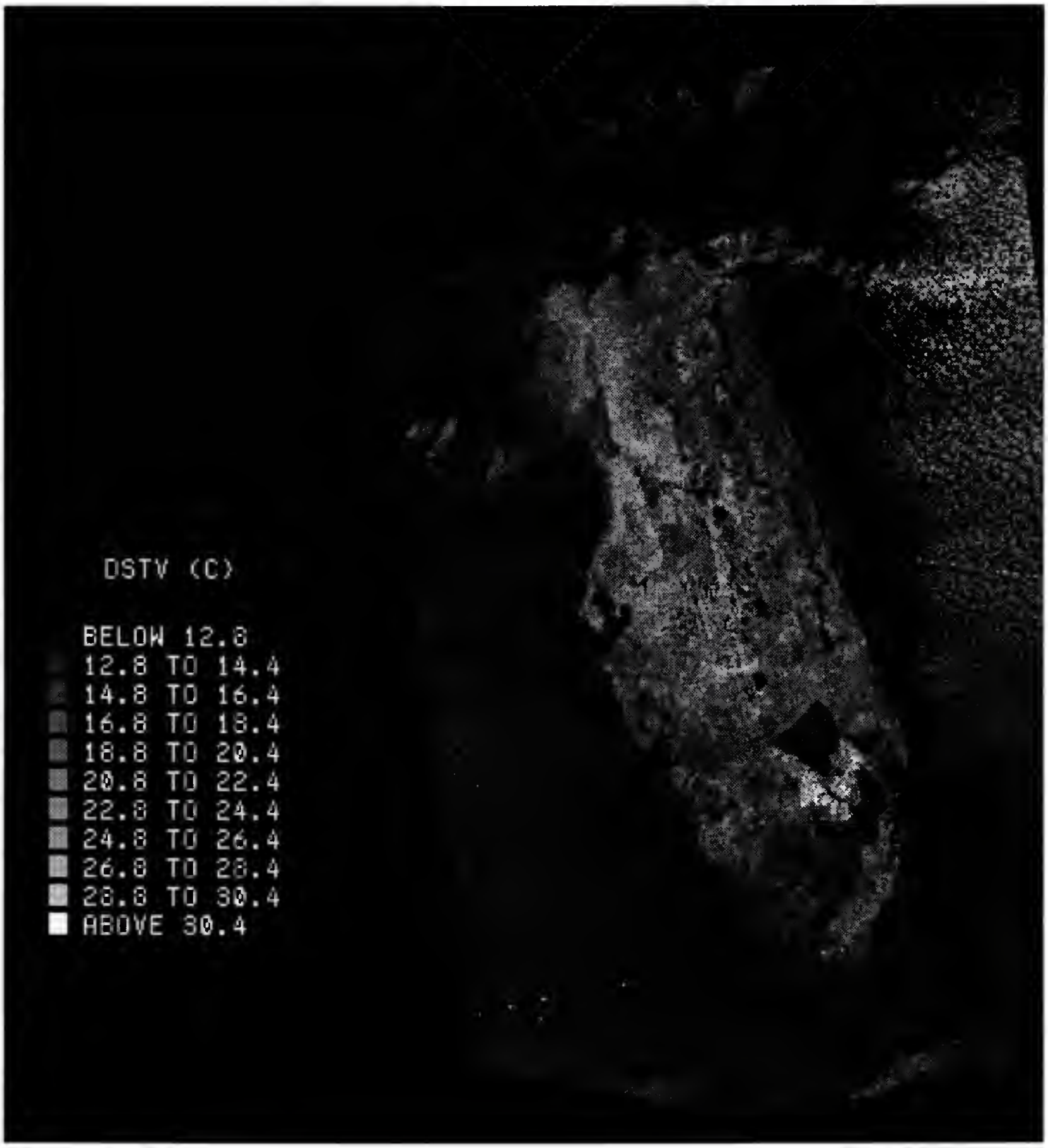


Figure 15. HCMM approximate-DSTV (winter) image.

conditions were sampled. Sampling times were from 0750 to 0940 h LST (early morning), and from 1230 to 1450 h LST (afternoon). Weather conditions were clear and sunny.

Surface temperature was measured with a set of three thermistor probes calibrated to ± 0.1 C. These were placed just beneath the soil surface, according to the technique described by Fuchs and Tanner (1968).

Soil samples were taken, just after the temperature measurements, with a sand auger in 8 cm increments to a depth of 40 cm, and placed in moisture-sealed plastic bags for later laboratory analysis. The increment of 8 cm was chosen to match the damping depth, $\underline{d}$ of equation 6, predicted for mineral soil under dry condition--the conservative case, which produces the smallest value of $\underline{d}$. Gravimetric soil-moisture analysis was performed with laboratory oven and scale. Because all of the sampling sites were in cleared and freshly-planted fields with no appreciable amount of vegetation nearby, no normalization for variation in vegetation effects was applied to the analysis of the DSTV/soil-moisture relation.

## Organic Soil Investigation

Organic soil (Pahokee muck) effects on DSTV were investigated at the Everglades Research and Education Center (EREC) located near Belle Glade, Florida. Soil type and drainage conditions of the experimental sugarcane fields are

typical of those found in the rest of the EAA (Appendix C, agricultural polygon number 49).

From 28 to 30 April 1992, twelve sites consisting of bare muck soil under the widest available variety of moisture conditions were sampled. Sampling times were from 0740 to 0940 h LST (early morning), and from 1440 to 1640 h LST (afternoon). Weather conditions were clear and sunny (south Florida dry season).

Surface temperature was measured with a set of three thermistor probes calibrated to ± 0.1 C. These were placed just beneath the soil surface, according to the technique described by Fuchs and Tanner (1968). Simultaneous air temperature was taken at 1 m height with the thermistor air-temperature sensor of an Everest Interscience model 210 radiometer.

Soil samples were taken, just after the temperature measurements, with a muck auger in 3 cm increments to a depth of 18 cm, and placed in moisture-sealed plastic bags for later laboratory analysis. The increment of 3 cm was chosen to match the damping depth, $\underline{d}$ of equation 6, predicted for organic soil under dry condition. Gravimetric soil-moisture analysis was performed with laboratory oven and scale.

Because many of the sampling sites were in clearings within or near fields of various crops such as mature sugarcane, young ratoon sugarcane, sod, rice, and vegetables, the well-known air-temperature normalization technique (Idso et al., 1976; Millard et al., 1978) was applied to the surface

temperature data to reduce the influence of variation in the transpiration of surrounding vegetation on the analysis of the DSTV/soil-moisture relation. The normalization used the equation (Millard et al., 1978):

$$DSTV_n = \frac{DATV_{avg}}{DATV} (DSTV) - DATV_{avg} \qquad [29]$$

where $DSTV_n$ is the normalized DSTV, DATV is the difference (C) between afternoon and morning air temperature for a given sample, and $DATV_{avg}$ is the average DATV from the air temperature data of all of the samples.

Vegetated Soil Investigation

Vegetation (grass) effects on DSTV were investigated at the Energy Research and Education Park and adjoining Biogas Production Research Park located at Gainesville, Florida. The soil was of the upland loamy sand type (Blichton sand) and drainage conditions were typical of those found in surrounding pasture areas.

On 13, 14, and 26 November and 5 and 6 December 1991, seven sites consisting of grass-covered soil under the widest available variety of moisture conditions were sampled. Sampling times were from 0830 to 0930 h LST (early morning), and from 1430 to 1540 h LST (afternoon). Weather conditions were clear and sunny.

Surface temperature was measured with a set of three thermistor probes calibrated to ± 0.1 C. These were placed

just beneath the vegetation surface. Simultaneous air temperature was taken at 1 m height with the thermistor air-temperature sensor of an Everest Interscience model 210 radiometer.

Soil samples were taken, just after the temperature measurements, with a sand auger in 8 cm increments to a depth of 48 cm, and placed in moisture-sealed plastic bags for later laboratory analysis. The increment of 8 cm was chosen to match the damping depth, $\underline{d}$ of equation 6, predicted for mineral soil under dry condition. Gravimetric soil-moisture analysis was performed with laboratory oven and scale.

Because the sampling sites had grass cover, the previously described air-temperature normalization technique was applied to the surface temperature data to reduce the influence of variation in grass transpiration on the analysis of the DSTV/soil-moisture relation.

## Soil Type Data

Polygons of soil type were digitized from a soil type map (USDA, 1982) for inclusion in the GIS. Broadly-defined soil types occurring at kilometer scale were selected for this research. There are two general soil types of potential interest to surface temperature studies--mineral and organic. In this research, further distinctions have been addressed based on drainage properties (especially the presence of very low, very high, or seasonally fluctuating water-table) and the presence of hardpan or limestone within root-zone depths.

One to three coverages (corresponding to the three climate zones) of each soil type were assembled from these digitized polygons. Certain soil types did not exist in all three climate zones. Soil types were of seven basic kinds--deep sand, upland loamy sand, flatwoods sand, coastal sand, sandy rockland, marly rockland, and organic. Their individual descriptions are given below. Further details concerning soil types can be obtained from various sources (Stewart et al., 1963; Brady, 1984; Sodek et al., 1990; Akin, 1991; Salisbury and D'Aria, 1992).

Mineral Soils

Deep sand. Deep sand includes deep, excessively-drained mineral soils that consist of sand throughout the root-zone and some distance below (a form of Entisol); the water-table is well below the root-zone. They are locally referred to as "sugar sands" (if white) or "buff sands" (if not). Except for preserves of the natural scrub, the land-cover has been changed to agricultural, urban, or mine use.

Upland loamy sand. Upland loamy sand includes deep, moderately-drained to well-drained mineral soils that consist of loamy sand with clayey subsurface horizons that are either high in base-saturation (Alfisols) or low in base-saturation (Ultisols); the water-table is well below the root-zone. Except for preserves of the natural upland mixed forest, the land-cover has been changed to agricultural and some urban use.

Flatwoods sand. Flatwoods sand includes shallow, poorly-drained, mineral soils that consist of acid-leached sand with subsurface horizons containing organic matter and aluminum oxides, bounded within the root-zone by a cemented-sand hardpan (Aquod Spodosols). Because the hardpan is an aquiclude, the water-table under natural conditions experiences a pronounced seasonal fluctuation--high (saturated near or at surface) in summer/fall, to low in winter/spring (Ziegler and Wolfe, 1961; Mullahey et al., 1992). Except for preserves of flatwoods forest and pine plantations, the land-cover has been changed to agricultural, urban, and mine use.

Coastal sand. Coastal sand includes the deep, variably-drained, miscellaneous coastal mineral soil associations of sand and/or shell with no subsurface horizons (Entisols). Portions of this coastal soil which are poorly drained (including those tidally submerged) remain under their natural cover of saltmarsh and mangrove swamp; those which are better-drained are now mostly under agricultural and especially urban use, except for preserves of coastal hammock and strand.

Sandy rockland. Sandy rockland includes shallow, well to poorly drained mineral soils consisting of sand (Entisols) or loamy sand (Ultisols, Alfisols) over limestone. The water-table can be either high (saturated near or at surface) or low, depending on local topography. Except for preserves of rockland hammock (high water-table) and calcareous hammock (low water-table), the land cover has been changed to agricultural or urban use.

Marly rockland. Marly rockland includes shallow, poorly drained mineral soils consisting of marl (a form of Entisol) over limestone. Marl is a gray, alkaline, clayey material composed of calcium carbonate that was precipitated on the foliage of certain aquatic plants--algae such as stonewort (Chara spp.) and angiosperms such as coontail-moss (Ceratophyllum demersum L.)--which grew in the area when it was covered by relatively deep fresh water; it is often mixed with fine sand and/or freshwater mollusk shells. The water-table can be either seasonally high (saturated near surface or submerged in summer/fall, drier in winter/spring) or relatively low (not seasonally submerged), depending on local topography. Agricultural and urban use has been limited to the low water-table areas, but has displaced much of the natural cover except in preserves of rockland hammock. The vast areas having a high water-table are mostly under the natural land-cover of wet-prairie and dwarf-cypress swamp.

## Organic Soils

Organic soil includes poorly drained soils consisting of a shallow to deep layer of muck (highly decomposed vegetation) or peat (slightly decomposed vegetation) over limestone or sand (Histosols). The substrate is not considered in this surface-temperature study, due to the previously mentioned thermal properties of organic soil ($d$ of equation 6). Under natural conditions, these soils are submerged (muck) or saturated (peat). Except for preserves of natural marsh or

bay swamp, the land-cover of organic soils has been changed to mostly agricultural use.

## Artificial Soil Type Change

There are two forms of artificial soil type change occuring at kilometer scale in Florida. One involves organic soil, and the other involves mineral soil.

Organic soil decrease. Subsidence of organic soil, due to drainage for agriculture, takes place due to dewatering and microbial breakdown (Jones, 1948; Snyder, 1978; Lucas, 1982). The present rate of subsidence of muck soils under agricultural use in the EAA is about 1 inch per year (Snyder, 1978). If the organic layer is completely lost in the EAA, the result will be a meso-scale change from organic to mineral (rockland) soil type. In this study, the surface temperature patterns of organic soil were analyzed under several land-cover conditions.

Wet clay increase. A phosphatic clay "soil" is gradually produced from phosphate mine settling ponds. If this situation remains unchanged (no future re-working), a wet clay soil sharing many of the characteristics of marl will have been deposited over large areas of former flatwoods sand. Depending upon the success of reclamation techniques, this soil may be used for row-crop or sod-farm agriculture, or managed as wet-prairie parkland. In this study, the surface temperature patterns of phosphate mines were compared to those

of other land-cover types, including titanium mines and agricultural subtypes.

## Land-Cover Data

Polygons of land-cover type were digitized from land-cover maps (CFW, 1973; USDA, 1980b; ABS, 1992a; FGFWFC, 1992) for inclusion in the GIS. Land-cover types occurring at meso-scale were selected for this research. Where map land-cover information was in doubt, aerial black and white photography from the University of Florida Map Library was photo-interpreted. This photography was taken from 1980 to 1985 at scales ranging from 1:20,000 to 1:40,000 by the United States Department of Agriculture. Ground visits were also made to many of the sites (especially the agricultural ones) during the course of this research. Details concerning the land-cover polygons are given in Appendix C.

One to three coverages (corresponding to the three climate zones) of each land-cover type were assembled from these digitized polygons. Certain land-cover types did not exist in all three climate zones. Land-cover types were of three basic kinds--natural, agricultural, and urban/industrial. There were also some land-cover types under special conditions.

### Natural Land-Cover

Many different natural land-cover types have been described in Florida (Jones, 1948; CFW, 1973; USDA, 1980b;

Morton, 1982; Clewell, 1985; USDA, 1989; FDNR, 1990). This research included 13 general types which occur at meso-scale (Figure 16). These include scrub, upland mixed forest, flatwoods forest, rockland hammock, coastal hammock, hardwood swamp, cypress swamp, bay swamp, mixed swamp, mangrove swamp, shrubby marsh, herbaceous freshwater marsh, and saltmarsh. Some of these contain subtypes (evergreen, deciduous, etc.) which were also studied.

Scrub forest. Scrub is a xeric type of forest found throughout the state on dry soils. Two subtypes are present in Florida--mixed scrub and evergreen scrub.

Mixed scrub is a dense to open xeric forest of mixed pine and deciduous broadleaf trees; it occurs on gently rolling terrain with well-drained to excessively-drained deep sand soil of the "buff sand" sort. It experiences frequent to occasional ground fire. Mixed scrub has an upper story of longleaf pine (Pinus palustris Mill.) and/or Choctawhatchee sand pine (Pinus clausa imuginata Ward)--in panhandle--or Ocala sand pine (Pinus clausa Chapm. ex Engelm.)--in north, mixed with the deciduous turkey oak (Quercus laevis Walt.), bluejack oak (Quercus incana Bartr.), Margaret oak (Quercus margaretta Ashe), and persimmon (Diospyros virginiana L.). There is an understory of deciduous Chapman oak (Quercus chapmanii Sarg.), scrub hickory (Carya floridana Sarg.)--in north, and Hercules'-club (Zanthoxylum clava-herculis L.). The typical composition is a mixed upper story of longleaf pine, turkey oak, and bluejack oak, an understory of mixed

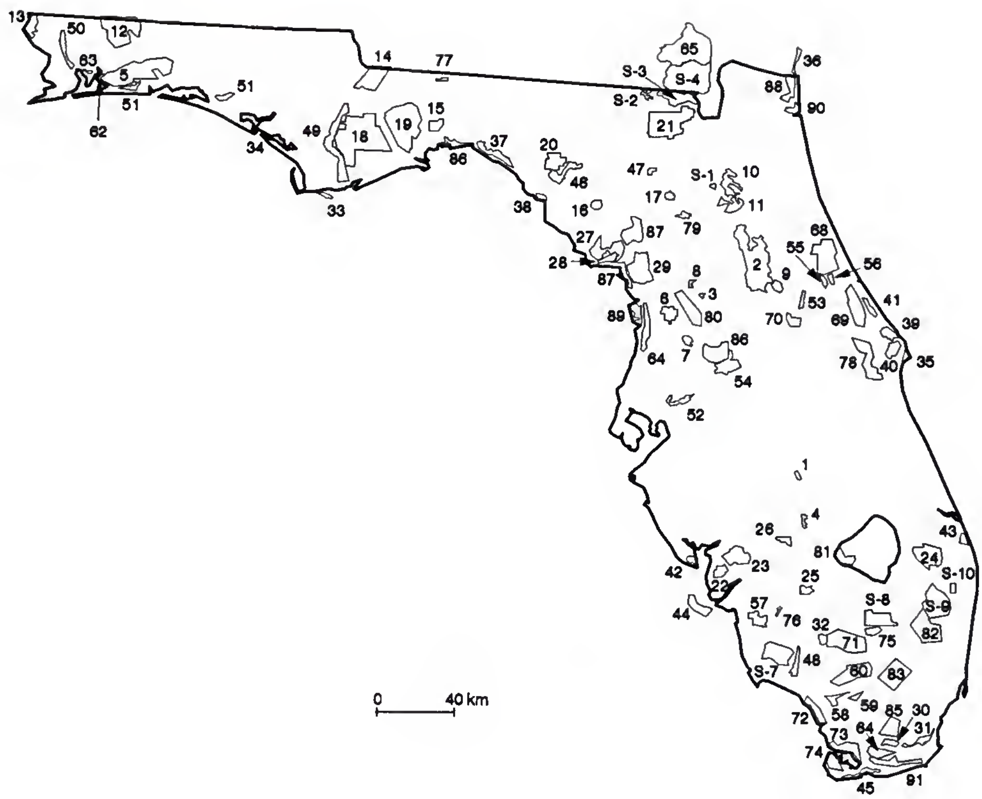

Figure 16. Natural land-cover polygons (see Appendix C for details).

deciduous Chapman oak, scrub hickory, and a mixed undergrowth including evergreen shrubs such as staggerbush (*Lyonia* spp.), weakleaf yucca (*Yucca flaccida* Haw.), and prickly-pear cactus (*Opuntia* spp.); deciduous shrubs such as sparkleberry (*Vaccineum arboreum* Marsh.), huckleberry (*Gaylussacia* spp.), Chickasaw plum (*Prunus angustifolia* Marsh.), dwarf hawthorn (*Crataegus uniflora* Muenchh.), sand holly (*Ilex ambigua* Michx.), tread-softly (*Cnidoscolus stimulosus* Michx.), and flag paw-paw (*Asimina* spp.); and wiregrass (*Aristida stricta* Michx.).

Evergreen scrub is a dense to open xeric forest of pine; it occurs on gently rolling terrain with acid, excessively-drained, deep sand soil of the "sugar sand" sort. It experiences occasional canopy fire. Evergreen scrub has an upper story of Ocala sand pine and/or south Florida slash pine (*Pinus elliotii densa* Little)--in south Florida only. There is an understory consisting of evergreen sand live oak (*Quercus geminata* Small) and/or dwarf live oak (*Quercus pumila* Walt.). The typical composition is Ocala sand pine upper story with an undergrowth of shrubs dominated by the evergreen Florida-rosemary (*Ceratiola ericoides* Michx.), Archbold oak (*Quercus inopina* Swingle), scrub oak (*Quercus minima* Sarg.), myrtle oak (*Quercus myrtifolia* Willd.), scrub palmetto (*Sabal etonia* Swingle), saw-palmetto (*Serenoa repens* Bartr.), staggerbush, shiny deerberry (*Vaccineum myrsinites* Lam.), tallow-wood (*Ximenia americana* L.)--in south Florida only, prickly-pear cactus, weakleaf yucca, gopher-apple (*Licania*

<u>michauxii</u> Prance), greenbrier (<u>Smilax</u> spp.), and ground lichen (<u>Cladonia</u> spp).

<u>Upland mixed forest.</u> Upland mixed forest is a dense to open forest of mixed pine and both deciduous and evergreen broadleaf trees; it is found on gently rolling terrain with well-drained to moderately well-drained deep loamy sand soil. It consists, at kilometer-scale, of a mixture of two components--"pine-oak-hickory woods" and "mesic hammock." The open pine-oak-hickory woods occupies the well-drained soil and experiences frequent ground fire; the dense mesic hammock occupies the moderately well-drained soil and seldom experiences any fire. The upper story consists of longleaf pine, loblolly pine (<u>Pinus taeda</u> L.), slash pine (<u>Pinus elliotii</u> Engelm.), or spruce pine (<u>Pinus glabra</u> Walt.), mixed with the deciduous southern red oak (<u>Quercus falcata</u> Michx.), post oak (<u>Quercus stellata</u> Wang.), Margaret oak, beech (<u>Fagus grandifolia</u> Ehrh.)--in panhandle, tulip-tree (<u>Liriodendron tulipifera</u> L.)--in panhandle, white ash (<u>Fraxinus americana</u> L.), southern sugar maple (<u>Acer saccharum</u> Marsh.), mockernut hickory (<u>Carya tomentosa</u> Poir.), pignut hickory (<u>Carya glabra</u> Mill.), sweetgum (<u>Liquidambar styraciflua</u> L.), sugarberry (<u>Celtis laevigata</u> Willd.), and basswood (<u>Tilia caroliniana</u> Mill.), and the evergreen laurel oak (<u>Quercus hemisphaerica</u> Bartr.), water oak (<u>Quercus nigra</u> L.), live oak (<u>Quercus virginiana</u> Mill.), southern magnolia (<u>Magnolia grandiflora</u> L.), and red bay (<u>Persea borbonia</u> L.). There is an understory consisting of the deciduous dogwood (<u>Cornus florida</u> L.),

fringe-tree (Chionanthus virginicus L.), red mulberry (Morus rubra L.), hornbeam (Carpinus caroliniana Walt.), and hop-hornbeam (Ostrya virginiana Mill.), and the evergreen sweetleaf (Symplocos tinctoria L.) and American holly (Ilex opaca Ait.). The typical composition is an upper story of mixed longleaf pine, loblolly pine, southern red oak, Margaret oak, laurel oak, live oak, mockernut hickory, pignut hickory, sweetgum, and sugarberry, with an understory of dogwood, hornbeam, and hop-hornbeam, and an undergrowth of mixed shrubs such as the evergreen yaupon holly (Ilex vomitoria Ait.), wax-myrtle (Myrica cerifera L.), and greenbrier, and the deciduous hawthorn (Crataegus spp.), pawpaw (Asimina parviflora Michx.), trailing chinquapin (Castanea alnifolia Nutt.), beautyberry (Callicarpa americana L.), witch-hazel (Hamamelis virginiana L.), wild bunch grape (Vitis aestivalis Michx.), wild muscadine grape (Vitis rotundifolia Michx.), leatherleaf clematis (Clematis reticulata Walt.), wild-indigo (Baptisia spp.), milk-pea (Galactia spp.), butterfly-pea (Clitoria mariana L.), poison-oak (Toxicodendron toxicarium Salisb.), and Virginia creeper (Parthenocissus quinquefolia L.).

Flatwoods forest. Flatwoods forest is a dense to open evergreen forest of pine; it occurs on very level terrain with flatwoods sand soil having a hardpan. It experiences large seasonal water-table fluctuations, frequent ground fire, and occasional canopy fire.

In panhandle and north Florida, flatwoods forest has a dense upper story consisting of longleaf pine, loblolly pine,

pond pine (Pinus serotina Michx.), or slash pine (Mullahey and Tanner, 1992). The typical composition is an upper story of slash or longleaf pine, with an undergrowth dominated by evergreen shrubs such as saw-palmetto, gallberry holly (Ilex glabra L.), staggerbush, tar-flower (Befaria racemosa Vent.), and wax-myrtle, but also including the deciduous blazing-star (Liatris spp.), beautyberry, winged sumac (Rhus copallina L.), and huckleberry, as well as grasses such as three-awn (Aristida spp.) and Indian-grass (Sorghastrum spp.). It also includes scattered dome swamps and/or natural clearings of marsh or wet-prairie.

In south Florida, flatwoods forest has an open upper story consisting of south Florida slash pine (Mullahey and Tanner, 1992). Undergrowth includes those species from north Florida. The typical composition is an upper story of south Florida slash pine, with an undergrowth dominated by saw-palmetto, gallberry holly, and wax-myrtle, but also including the deciduous blazing-star and huckleberry, as well as grasses such as three-awn and Indian-grass. It also includes scattered dome swamps and/or natural clearings of marsh or wet-prairie.

Rockland hammock. Rockland hammock is a dense forest of mixed pine and/or red-cedar and both evergreen and deciduous broadleaf trees; it occurs on level or slightly elevated terrain with well to poorly-drained shallow sandy or marly soil over limestone. It experiences frequent to rare ground fire. There are two subtypes--"rockland hammock" and

"calcareous hammock". The rockland hammock subtype occurs on rockland with a relatively high water-table in north and south florida; the calcareous hammock subtype occurs on rockland with a relatively low water-table in north Florida.

In north Florida, the rockland hammock subtype has a mixed upper story of slash pine, southern red-cedar (Juniperus silicicola Small), and the evergreen live oak, cabbage palm (Sabal palmetto Walt.), southern magnolia, sweetbay magnolia (Magnolia virginiana L.), red bay, laurel oak, and water oak, and the deciduous Florida elm (Ulmus americana floridana Chapm.), basswood, and swamp ash (Fraxinus pauciflora Nutt.). There is an understory consisting of evergreen dahoon holly (Ilex cassine L.), American holly, and laurelcherry (Prunus caroliniana Mill.). The typical composition is a mixed upper story of slash pine, red-cedar, live oak, laurel oak, Florida elm, Carolina basswood, swamp ash, and cabbage palm, with an understory of dahoon holly and laurelcherry, and an undergrowth of mixed shrubs such as the evergreen bluestem palm (Sabal minor Jacq.) and greenbrier, and the deciduous climbing buckthorn (Sageretia minutiflora Michx.). This subtype rarely experiences any fire.

In north Florida, the calcareous hammock subtype has a mixed upper story of longleaf pine, loblolly pine, red-cedar, and the deciduous bluff oak (Quercus durandii Buckl.), Shumard oak (Quercus shumardii Buckl.), mockernut hickory, basswood, sugarberry, and Florida elm. There is an understory consisting of the deciduous Carolina buckthorn (Rhamnus

caroliniana Walt.), red buckeye (Aesculus pavia L.), rusty black-haw viburnum (Viburnum rufidulum Raf.), dogwood, fringe-tree, hornbeam, and hop-hornbeam, and the evergreen laurelcherry, red bay, and gum-bumelia (Bumelia lanuginosa Michx.). The typical composition is a mixed upper story of longleaf pine, loblolly pine, red-cedar, bluff oak, and mockernut hickory, with an understory of Carolina buckthorn, rusty black-haw viburnum, dogwood, hornbeam, hop-hornbeam, laurelcherry, red bay, and gum-bumelia, and a mixed undergrowth including the evergreen needle palm (Rhapidophyllum hystrix Pursh), buckthorn bumelia (Bumelia reclinata Michx.), snowberry (Symphoricarpos spp.), ebony spleenwort fern (Asplenium platyneuron L.), greenbrier, and coontie (Zamia floridana A. DC.), and the deciduous bracken fern (Pteridium aquilinum L.) (Mullahey and Tanner, 1992). This subtype experiences occasional ground fire. Although calcareous hammock once covered substantial portions of Alachua, Gilchrist, and Levy counties, it has been almost completely replaced at kilometer scale by agriculture--unlike the rockland hammock subtype, which has been partly preserved at kilometer scale in south Florida parkland and in north Florida undeveloped hammock-land. Calcareous hammock is modeled in this study by substituting the thermal data of the natural land-cover type having the most similar vegetation and soil type--Upland Mixed Forest.

In south Florida, the rockland hammock subtype has two components at kilometer scale--"tropical hammock" and

"Everglades flatwoods" (Mullahey and Tanner, 1992). The tropical hammock component occurs on sites that rarely experience fire; the Everglades flatwoods component occurs on sites that are subject to a seasonal flood and fire regime. The typical composition of the tropical hammock component is an upper story of south Florida slash pine mixed with the evergreen live oak, laurel oak, cabbage palm, strangler fig (Ficus aurea Nutt.), shortleaf fig (Ficus citrifolia Mill.), false-mastic (Mastichodendron foetidissimum Cronq.), wild-tamarind (Lysiloma bahamensis L.), pigeon-plum (Coccoloba diversifolia Jacq.), mahogany (Sweitenia mahogani L.), willow-bustic (Dipholis salicifolia L.), red bay, paradise-tree (Simarouba glauca DC.), and poisonwood (Metopium toxiferum Krug & Urban), and the deciduous peninsular persimmon (Diospyros virginiana mosieri Sarg.), sugarberry, and gumbo-limbo (Bursera simaruba L.), with an understory of the evergreen snakebark (Colubrina arborescens Sarg.), smooth snakebark (Colubrina elliptica Brinz. & Stern), satinleaf (Chrysophyllum oliviforme L.), black ironwood (Krugiodendron ferreum Urb.), wingleaf soapberry (Sapindus saponaria L.), and silver palm (Coccothrinax argentata Bailey), and the deciduous Geiger-tree (Cordia sebestena L.), and an undergrowth consisting of the evergreen saw-palmetto, wax-myrtle, tough bumelia (Bumelia tenax L.), saffron-plum (Bumelia celastrina HBK.), blackbead (Pithecellobium spp.), marlberry (Ardisia escallonioides Schiede & Deppe), glamberry (Byrsonima lucida DC.), balsamo (Psychotria spp.), myrsine (Myrsine guianensis

Kuntze), snowberry, tallow-wood, coontie, greenbrier, and stopper (Eugenia spp.), and the deciduous winged sumac and bracken fern. The typical composition of the Everglades flatwoods component is an upper story of south Florida slash pine mixed with cabbage palm, with no understory, and a fire-trimmed undergrowth of saw-palmetto, wax-myrtle, coontie, greenbrier, and bracken fern.

Coastal hammock. Coastal hammock is a dense to open, dissected forest with an upper story of pine mixed with mostly evergreen broadleaf trees; it occurs along both coasts. It consists, at kilometer scale, of a mixture of three components--a dense forest of "coastal hammock" on well to poorly drained coastal sand or shell middens, a more open "coastal strand" on well-drained stabilized dune sand, and a non-forested "coastal swale" on poorly drained coastal sand. These components rarely experience any fire. In the panhandle and north, the typical composition is an upper story of slash pine, sand pine, and southern red-cedar, mixed with the evergreen wild olive (Osmanthus americanus L.), live oak, southern magnolia, sand live oak, myrtle oak, cabbage palm, red bay, and American holly, and the deciduous sweet acacia (Acacia smallii Isely) and Hercules'-club, with an understory of the evergreen dahoon holly, and an undergrowth of mostly evergreen broadleaf shrubs such as yaupon holly, wax-myrtle, saw-palmetto, myrsine, prickly-pear cactus, bayonet bush (Yucca aloifolia L.), greenbrier, and Florida-privet (Forestiera segregata Jacq.), and the needle-leaved Florida-

rosemary. In the south, the typical composition is an upper story of south Florida slash pine and sand pine, mixed with the evergreen sand live oak, myrtle oak, cabbage palm, red bay, sea-grape (Coccoloba uvifera Jacq.), mahoe (Hibiscus tiliaceus L.), portia-tree (Thespesia populnea Soland.)--an exotic, pigeon-plum, strangler fig, wild-tamarind, paradise-tree, mahogany, poisonwood, and false-mastic, and the deciduous gumbo-limbo, with an understory of the evergreen dahoon holly, blackbead, caper-tree (Capparis spp.), and snakebark, and the deciduous Geiger-tree, and an undergrowth of mostly evergreen broadleaf shrubs such as the cocoplum (Chrysobalanus icaco L.), tallow-wood, wax-myrtle, saw-palmetto, marlberry, myrsine, Florida-privet, greenbrier, prickly-pear cactus, prickly-apple cactus (Cereus spp.), lantana (Lantana camara L.)--an exotic, bayonet bush, balsamo, necklace-pod (Sophora spp.), and seven-year apple (Casasia clusiaefolia Urban), and the needle-leaved Florida-rosemary.

Hardwood swamp. Hardwood swamp is a dense forest of broadleaf trees; it occurs on depressed terrain with poorly-drained (seasonally submerged) soil of variable type. It is almost never subject to fire. There are two subtypes--"evergreen hardwood swamp"--which occupies relatively drier sites, and "deciduous hardwood swamp"--which occupies the wetter sites.

In north Florida, the evergreen hardwood swamp subtype has an upper story of the evergreen live oak, laurel oak, and water oak, cabbage palm, and southern magnolia. There is an

understory, consisting of the evergreen red bay, swamp bay (Persea palustris Raf.), dahoon holly, myrtle-dahoon holly (Ilex myrtifolia Walt.), American holly, sweetbay magnolia, laurelcherry, and the deciduous pop ash (Fraxinus caroliniana Mill.), wafer-ash (Ptelea trifoliata L.), and basswood. There are usually a few scattered specimens of the deciduous swamp ash, black-gum tupelo (Nyssa biflora Walt.), and bald-cypress (Taxodium distichum L.). The typical composition is an upper story of live oak, laurel oak, water oak, cabbage palm, and southern magnolia, with an understory of myrtle-dahoon holly, red bay, swamp bay, and an undergrowth of bluestem palm, ferns, and mixed broadleaf shrubs.

In south Florida, the evergreen hardwood swamp subtype has an upper story of the evergreen live oak, laurel oak, cabbage palm, Florida royal palm (Roystonea elata Harper), false-mastic, shortleaf fig, strangler fig, willow-bustic, mahogany, pigeon-plum, and wild-tamarind, and scattered specimens of the deciduous gumbo-limbo, red maple (Acer rubrum L.), Florida elm, swamp ash, persimmon, sugarberry, pignut hickory, black-gum tupelo, and bald-cypress. There is an understory, consisting of the evergreen Everglades palm (Paurotis wrightii L.), dahoon holly, sweetbay magnolia, and red bay, and the deciduous pond-apple (Annona glabra L.) and red mulberry. The typical composition is an upper story of live oak, laurel oak, cabbage palm, Florida royal palm, and willow-bustic, with an understory of dahoon holly, red bay,

Everglades palm, and pond-apple, and an undergrowth of ferns and predominantly evergreen broadleaf shrubs.

In panhandle and north Florida the deciduous hardwood swamp subtype has an upper story of the deciduous water-tupelo (Nyssa aquatica L.), red maple, boxelder maple (Acer negundo L.), swamp ash, green ash (Fraxinus pennsylvanica, Marsh.)--in panhandle, pumpkin ash (Fraxinus profunda Bush), cottonwood (Populus spp.)--in panhandle, river birch (Betula nigra L.), water hickory (Carya aquatica Michx.), bitternut hickory (Carya cordiformis Wang.)--in panhandle, pignut hickory, black willow (Salix nigra Marsh.)--in panhandle, Carolina basswood, soapberry (Sapindus marginatus Willd.), swamp-chestnut oak (Quercus michauxii Nutt.), overcup oak (Quercus lyrata Walt.), willow oak (Quercus phellos L.)--in panhandle, water-locust (Gleditsia aquatica Marsh.), black-gum tupelo, sourgum tupelo (Nyssa sylvatica Marsh.), sweetgum, water-elm (Planera aquatica Walt.), tulip-tree, American sycamore (Platanus occidentalis L.)--in panhandle, sugarberry, winged elm (Ulmus alata Michx.), Florida elm, red mulberry, and persimmon. There is usually a very narrow strip of bald-cypress along the edges of rivers and lakes, and there are usually some scattered specimens of the evergreen southern magnolia and sweetbay magnolia. There is an understory consisting of the deciduous pop ash, Carolina willow (Salix caroliniana Michx.), silverbell (Halesia spp.)--in panhandle, snowbell (Styrax spp.), and wafer-ash. The typical composition is an upper story of various deciduous hardwoods (dominated locally by

water-tupelo, red maple, green ash, cottonwood, willow oak, black gum tupelo, river birch, or water-elm, but usually a mixture of red maple, swamp ash, water hickory, basswood, swamp-chestnut oak, water-locust, black-gum tupelo, sweetgum, sugarberry, and Florida elm), with an understory of pop ash, Carolina willow, silverbell--in panhandle, and wafer ash, and an undergrowth of bluestem palm, switchcane (Arundinaria spp.), and mixed evergreen and deciduous broadleaf shrubs and vines.

Cypress swamp. Cypress swamp is a dense to open forest of deciduous cypress trees; it occurs on depressed terrain with poorly-drained (seasonally submerged) soil of variable type. It is seldom subject to fire. There are two subtypes--"cypress swamp" and "dwarf-cypress swamp". The dense cypress swamp subtype occurs on soil of variable type--sometimes a shallow layer over limestone, or elongated pockets of deep organic soil in "strand" limestone channels; the more open dwarf-cypress swamp subtype occurs on marly rockland in south Florida.

In north Florida, the cypress swamp subtype consists of bald-cypress and/or pond-cypress (Taxodium ascendens Brongn.), with some scattered specimens of the evergreen cabbage palm and the deciduous green ash, pumpkin ash, swamp ash, red maple, black-gum tupelo, persimmon, sugarberry, pignut hickory, water hickory, and Florida elm. There is an understory, consisting of the evergreen myrtle-dahoon holly, sweetbay magnolia, red bay, swamp bay, loblolly-bay (Gordonia

*lasianthus* L.), and laurelcherry, and the deciduous pop ash and Carolina willow. The typical composition is an upper story dominated by bald-cypress or pond-cypress, with an understory of myrtle-dahoon holly, red bay, pop ash, and Carolina willow, and an undergrowth of bluestem palm, ferns, mixed evergreen and deciduous broadleaf shrubs, and aquatic herbs.

In south Florida, the cypress swamp subtype has an upper story of bald-cypress or pond-cypress, with some scattered specimens of the evergreen cabbage palm and Florida royal palm, and the deciduous black-gum tupelo, gumbo-limbo, red maple, persimmon, sugarberry, Florida elm, and pignut hickory. There is an understory, consisting of the evergreen dahoon holly, red bay, Everglades palm, sweetbay magnolia, and the deciduous pond-apple, pop ash, and Carolina willow. The typical composition is an upper story of bald-cypress, with an understory of dahoon holly, red bay, pond-apple, pop ash, and Carolina willow, and an undergrowth of ferns, mixed evergreen and deciduous broadleaf shrubs, and aquatic herbs.

In south Florida, the dwarf-cypress subtype has a dense to open upper story of pond-cypress, which is usually very stunted. It has much less understory than the cypress swamp subtype. There are scattered clearings of wet-prairie vegetation (see under Marsh). The typical composition is an upper story of pond-cypress, with an undergrowth dominated by the evergreen shrubs tough bumelia and saffron-plum, as well

as ferns and aquatic herbs, with scattered clearings of wet-prairie grasses.

Bay swamp. Bay swamp is a dense forest having some combination of evergreen broadleaf trees with pine, white-cedar, and/or deciduous cypress; it occurs on depressed terrain with poorly-drained organic soil. It is seldom subject to fire, but under drainage and/or drought impact, bay swamp can suffer catastrophic soil and canopy fire.

Bay swamp has an upper story of scattered pond pine, slash pine, loblolly pine, Atlantic white-cedar (Chamaecyparis thyoides L.)--in panhandle, southern red-cedar, and/or the deciduous pond-cypress or bald-cypress, mixed with the evergreen sweetbay magnolia, wild olive, cabbage palm, southern magnolia, live oak, and laurel oak, and the deciduous swamp ash, red maple, Carolina basswood, pignut hickory, and sweetgum. There is an understory, consisting of the evergreen myrtle-dahoon holly, red bay, swamp bay--in panhandle, loblolly-bay--in north, and laurelcherry, and the deciduous silky-Camellia. The typical composition is an upper story of mixed slash pine, pond pine, white-cedar, pond-cypress, sweetbay magnolia, southern magnolia, and wild olive, with an understory of myrtle-dahoon holly, red bay, swamp bay, and loblolly-bay, and a mixed undergrowth consisting of the evergreen staggerbush, dog-hobble (Leucothoe spp.), titi (Cyrilla racemiflora L.), and black-titi (Cliftonia monophylla Lam.), and the deciduous blueberry (Vaccineum corymbosum L.),

red chokeberry (Aronia arbutifolia L.), possum-haw viburnum (Viburnum nudum L.), and ferns.

Mixed swamp. Mixed swamp is a dense forest having some combination of pine with cypress swamp, hardwood swamp, and/or bay swamp; it occurs on depressed terrain with poorly drained (seasonally submerged) soil of variable type--at kilometer scale in north Florida, a mixture of flatwoods sand and pockets of organic soil; and in south Florida, sandy rockland. It is not ordinarily subject to fire, but under drainage and/or drought impact, mixed swamp can suffer catastrophic canopy and/or soil fire. This has happened repeatedly in the Okeefenokee Swamp area, but is more rare in south Florida.

In north Florida, mixed swamp has a mixed upper story of slash pine, pond pine, loblolly pine, deciduous pond-cypress, and the evergreen live oak, laurel oak, water oak, wild olive, sweetbay magnolia, southern magnolia, and cabbage palm, and the deciduous black-gum tupelo, sourgum tupelo, swamp ash, red maple, Florida elm, and Ogeechee-lime tupelo (Nyssa ogeche Bartr.). There is an understory, consisting of the evergreen red bay, myrtle-dahoon holly, and loblolly-bay. The typical composition is a mixed upper story of slash pine, pond pine, pond-cypress, laurel oak, water oak, sweetbay magnolia, southern magnolia, wild olive, cabbage palm, black-gum tupelo, swamp ash, red maple, Florida elm, and Ogeechee-lime tupelo, with an understory of myrtle-dahoon holly, red bay, and loblolly bay, and an undergrowth of mixed evergreen and deciduous broadleaf shrubs.

In south Florida, mixed swamp has a mixed upper story of south Florida slash pine and deciduous bald-cypress, the evergreen live oak, cabbage palm, and strangler fig, and the deciduous red maple. It has an understory, consisting of the evergreen dahoon holly and red bay, and the deciduous Carolina willow. The typical composition is a mixed upper story of south Florida slash pine, bald-cypress, cabbage palm, and live oak, with an understory of dahoon holly and red bay, and an undergrowth of evergreen broadleaf shrubs.

Mangrove swamp. Mangrove swamp is a dense forest of evergreen broadleaf trees, dissected by a network of tidally flooded channels; it occurs on level coastal terrain with sandy/shelly soil. It is always wet, so is never subject to fire. Mangrove swamp has an upper story of the evergreen red mangrove (Rhizophora mangle L.), black mangrove (Avicennia germinans Stearn), white mangrove (Laguncularia racemosa Gaertn.), buttonwood (Conocarpus erecta L.), , blolly (Torrubia longifolia L.), and sea-grape. The typical composition is a solid stand of red mangrove (below high-tide line), black mangrove (at high-tide line), white mangrove (above high-tide line), and buttonwood (well above high-tide line), with undergrowth (if any) dominated by leather fern (Acrostichum danaeifolium Lansd. & Fisch.), coin vine (Dalbergia ecastophyllum L.), coastal moonflower-vine (Ipomoea tuba G. Don), and nickerbean (Caesalpinia spp.), and tidal channels of saltmarsh grasses (or open).

_Shrubby marsh._ Shrubby freshwater marsh is a dense growth of broadleaf shrubs; it occurs on poorly drained muck soil, and is common at kilometer scale only in south Florida. It experiences occasional to rare fire. There are two subtypes--"evergreen shrubby marsh" and "deciduous shrubby marsh".

The evergreen shrubby marsh subtype occupies sites with a relatively lower water-table. It consists of the evergreen wax-myrtle, red bay, saltbush (_Baccharis_ spp.), elderberry (_Sambucus simpsonii_ Rehder), Brazilian pepper-tree (_Schinus terebinthifolius_ Raddi)--an exotic, guava (_Psidium guajava_ L.)--an exotic, strawberry guava (_Psidium cattleyanum_ L.)--an exotic), wild papaya (_Carica papaya_ L.)--an exotic, lime prickly-ash (_Zanthoxylum fragara_ L.), castorbean (_Ricinus communis_ L.)--an exotic, Everglades cocoplum (_Chrysobalanus icaco pellocarpus_ DC.), and gallberry holly. The typical composition is a mixture of wax-myrtle (often dominant), elderberry, Brazilian pepper-tree, saltbush, guava, wild papaya, Everglades cocoplum, and castorbean.

The deciduous shrubby marsh subtype occupies sites with a relatively higher water-table. It consists of the deciduous pond-apple, buttonbush (_Cephalanthus occidentalis_ L.), Carolina willow, primrose-willow (_Ludwigia peruviana_ L.)--an exotic, rose mallow (_Hibiscus moscheutos_ L.), balloon-vine (_Cardiospermum halicacabum_ L.), bitter-gourd (_Momordica charantia abbreviata_ Ser.)--an exotic, creeping-cucumber (_Melothria pendula_ L.), maypops passionflower (_Passiflora_

*incarnata* L.), highbush blackberry (*Rubus argutus* Link), wild-yam (*Dioscorea bulbifera* L.)--an exotic, moonflower-vine (*Ipomea alba* L.)--an exotic, and pipevine (*Aristolochia* spp.). The typical composition is a mixture of Carolina willow (often dominant), buttonbush, pond-apple, primrose-willow, rose mallow, and vines.

Herbaceous freshwater marsh. Herbaceous freshwater marsh is a dense, quasi-evergreen growth of aquatic and emergent plants. It occurs on poorly drained soil. There are two subtypes--"marsh" and "wet-prairie". The marsh subtype occurs on submerged muck soil; the wet-prairie subtype occurs on seasonally-submerged marly rockland. This land-cover type seldom experiences fire.

In panhandle and north Florida, the marsh subtype consists of grasses (*Panicum* spp., *Paspalum* spp., etc.), sedges (*Carex* spp., *Cyperus* spp., etc.), bluestem/broomsedge (*Andropogon* spp.), rushes (*Juncus* spp.), bulrushes (*Scirpus* spp.), clubhead cutgrass (*Leersia hexandra* Sw.), toothache-grass (*Ctenium aromaticum* Walt.), Muhly-grass (*Muhlenbergia* spp.), reed (*Phragmites communis* Trin.), southern wild-rice (*Zizaniopsis miliacea* Michx.), Atamasco lily (*Zephyranthes atamasco* L.), spider lily (*Hymenocallis rotata* Ker-Gawl.), swamp lily (*Crinum americanum* L.), bog-buttons (*Lachnocaulon* spp.), fireflag (*Thalia geniculata* L.), blue-flag iris (*Iris virginica* L.), yellow canna (*Canna flaccida* Salisb.), maidencane (*Panicum hemitomon* Schult.), sawgrass (*Cladium jamaicense* Crantz), and cattail (*Typha* spp.), with some

broadleaf herbs such as pickerel-weed (*Pontederia* spp.), tuckahoe (*Peltandra virginica* Schott & Endl.), arrowhead (*Sagittaria* spp.), wild taro (*Colocasia esculenta* L.)--an exotic, water-lily (*Nymphaea* spp.), water-hyacinth (*Eichhornia crassipes* Mart.)--an exotic, water-lettuce (*Pistia stratiotes* L.), chain fern (*Woodwardia* spp.), cinnamon fern (*Osmunda cinnamomea* L.), alligator-weed (*Alternanthera philoxeroides* Mart.)--an exotic, elodea (*Egeria densa* Planch.)--an exotic, hydrilla (*Hydrilla verticillata* L.f.)--an exotic, lotus (*Nelumbo* spp.), bladderwort (*Utricularia* spp.), floating-hearts (*Nymphoides* spp.), smartweed (*Polygonum* spp.), bindweed (*Calystegia* spp.), pipevine, pennywort (*Hydrocotyle* spp.), spatterdock (*Nuphar luteum* L.), black-eyed Susan (*Rudbeckia* spp.), coontail-moss, and filamentous algae (periphyton). The typical composition is a mixture of grasses, sedges, rushes, cattail, pickerel-weed, smartweed, arrowhead, wild taro, water-lily, water-hyacinth, water-lettuce, lotus, spatterdock, alligator-weed, floating-hearts, smartweed, and pennywort.

In south Florida, the marsh subtype consists of the marsh plants listed above. There are also some scattered tree-islands, which are small examples of shrubby marsh or hardwood swamp. The typical composition in undisturbed areas is sawgrass, bladderwort, coontail-moss, water-lily, and spatterdock; the composition in hydrologically disturbed areas is cattail, rushes, wild-sugarcane (*Saccharum officinarum* L.), maidencane, pickerel-weed, arrowhead, water-hyacinth, water-lettuce, wild taro, alligator-weed, and mats of periphyton.

In south Florida, the wet-prairie subtype consists of the south Florida marsh plants, plus beakrush (Rhynchospora spp.), poverty-grass (Aristida purpurescens Poir.), broomsedge, switch-grass (Aristida patula Chapm. ex Nash), maidencane, foxtail grass (Setaria spp.), sand cordgrass (Spartina bakeri Merr.), gulf-dune paspalum (Paspalum monostachyum L.), little-bluestem (Schizachyrium scoparium Michx.), little blue-maidencane (Amphicarpum muhlenbergianum Schult.), spikerush (Eleocharis spp.), bulrush, leather fern, cinnamon fern, and St. Johns-wort (Hypericum spp.). There are also some scattered tree-islands, which are small examples of shrubby marsh or dwarf-cypress swamp. The typical composition is a mixture of beakrush, poverty-grass, switch-grass, broomsedge, foxtail-grass, gulf-dune paspalum, sand cordgrass, little-bluestem, little blue-maidencane, spikerush, bulrush, pickerel-weed, arrowhead, cattail, fireflag, and St. Johns-wort.

Saltwater/brackish marsh. Herbaceous saltwater/brackish marsh is a dense, quasi-evergreen growth of mostly grassy aquatic plants along quieter parts of the sea-coast. There are two subtypes--"saltmarsh" and "brackish marsh". The saltmarsh subtype occurs on sand/mud soil in panhandle and north Florida; the brackish marsh subtype occurs on marly rockland in south Florida. This land-cover type rarely experiences any fire.

In panhandle and north Florida, the saltmarsh subtype consists primarily of grasslike plants such as sawgrass,

rushes, saltmarsh cordgrass (Spartina spp.), seashore saltgrass (Distichlis spicata L.), knotgrass (Paspalum distichum L.), seashore dropseed (Sporobolus virginicus L.), cattail, sedges, and broadleaf halophytic herbs such as samphire (Salicornia spp.), sea-purslane (Sesuvium portulacastrum L.), saltwort (Batis maritima L.), beach-carpet (Philoxerus vermicularis R. Br.), sea-lavender (Limonium carolinianum Walt.), sea-blite (Suaeda linearis Moq.), matchflower (Lippia nodiflora L.), pennywort, wild-savory (Calamintha coccinea Nutt.), matrimony-vine (Lycium carolinianum Walt.), marsh-elder (Iva spp.), and sea-oxeye daisy (Borrichia frutescens L.). The typical composition is a mixture of saltmarsh cordgrass, seashore saltgrass, knotgrass, seashore dropseed, rushes, sedges, sea-lavender, samphire, pennywort, pony-foot, wild-savory, marsh-elder, and glasswort.

In south Florida, the brackish marsh subtype consists of the above saltmarsh plants plus leather fern, Virginia wild-rye (Elymus virginicus L.), reed, marsh-mallow (Hibiscus spp.), and Wedellia-vine (Wedelia glauca Ort.)--an exotic. The typical composition is a mixture of spikerush, sawgrass, leather fern, cattail, Virginia wild-rye, saltmarsh cordgrass, glasswort, rushes, sedges, samphire, pennywort, swamp lily, and marsh-mallow.

## Agricultural Land-Cover

Many different agricultural land-cover types exist in Florida. This research included five general types which occur at meso-scale (Figure 17). These consist of row-crops, pasture/range, pasture/sod, citrus orchard, and mixed agriculture.

Row-crops. Row-crops agriculture consists of seasonal crops on tilled land; the crops provide only partial coverage of the soil even at crop maturity. It is practiced on all soil types (Hochmuth and Hanlon, 1989). Row-crops are always carefully drained, irrigated, and fertilized, and sometimes planted in plastic mulch (Hochmuth and Hanlon, 1989; Clark et al., 1993). Irrigation is performed mainly by seepage (pumping into ditches) or sprinkler gun (travelling high-pressure sprinkler), depending on local soil conditions and groundwater supplies (Smajstrla et al., 1993). There are spring, summer, fall, and winter crop seasons, and there is usually a rotation of the exact crop species from season to season. Spring row-crops consist of tomato (*Lycopersicon esculentum* Mill.), pepper (*Capsicum annuum* L.), potato (*Solanum tuberosum* L.), eggplant (*Solanum melongena* L.), cantaloupe (*Cucumis melo* L.), watermelon (*Citrullis lanatus* Thunb.), sunflower (*Helianthus annuus* L.), and strawberry (*Fragaria* spp.). Summer row-crops consist of long-season/heat-tolerant crops such as soybean (*Glycine max* L.), peanut (*Arachis hypogaea* L.), sweet-potato (*Ipomoea batatas*,

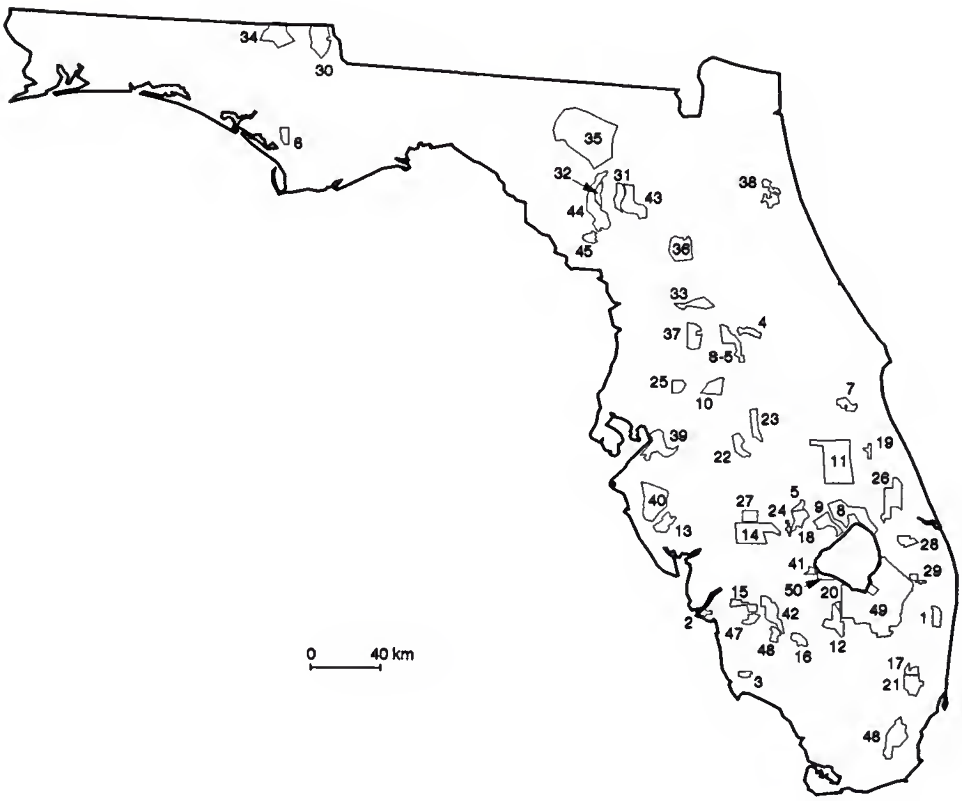


Figure 17. Agricultural land-cover polygons (see Appendix C for details).

L.), okra (Hibiscus esculentus L.), tobacco (Nicotiana tabacum L.), and cotton (Gossypium hirsutum L.), or fallow cover-crops such as hairy-indigo (Indigofera hirsuta Harv.) or sudangrass (Sorghum spp. hybrid). Fall row-crops consist of peppers and beans (Phaseolus spp.). Winter row-crops consist of lettuce (Lactuca sativa L.), cabbage (Brassica oleracea capitata L.), kale/collard (Brassica oleracea acephala L.), cucumber (Cucumis sativa L.), squash/zucchini/calabaza (Cucurbita pepo L.), cauliflower/broccoli (Brassica oleracea botrytis L.), Chinese cabbage (Brassica spp.), carrot (Daucus carota L.), endive/escarole (Cichorium endiva L.), radish (Raphanus sativus L.), celery (Apium graveolens L.), parsley (Apium petroselinum L.), onion (Allium spp.), and pepper. Row-crops have been cultivated in north and panhandle Florida since pre-Columbian times (Goggin, 1975).

Pasture/range. This type occurs primarily on flatwoods sand and sandy rockland. Pasture consists of improved pasture and paddocks; it is usually drained, sometimes fertilized, and sometimes irrigated--mainly by seepage (Smajstrla et al., 1993). Pasture grasses include the cultivated bahiagrass (Paspalum notatum Fluegge), centipedegrass (Eremochloa ophiuroides Munro), and Bermudagrass (Cynodon dactylon L.).

Range consists of unimproved pasture, with many weeds and scattered patches of forest, shrubs, and/or marsh; it is usually drained, but little other maintenance is supplied other than a burning every two to four years (Mullahey and Tanner, 1992). Range grasses include a wide variety of wild

marsh and wet-prairie grasses in addition to the cultivated grasses (Mullahey and Tanner, 1992).

Pasture and range are usually mixed at kilometer scale. Most of the grasses involved are quasi-evergreen. Pasture/range agriculture has been practiced in panhandle and north-central Florida since colonial times (Goggin, 1975), and in south-central Florida mainly since the 1870s (FDA, 1954).

Pasture/sod. This agriculture type occurs mainly on organic soils (McCarty and Cisar, 1990). Pasture and sod-farm are usually mixed at kilometer scale. Pasture component consists of improved pasture; it is always drained, and irrigated (when necessary) by seepage (Smajstrla et al., 1993).

Sod-farm component consists of lawn-grasses grown for the landscaping trade--turfs are periodically harvested in strips which then regrow quickly (propagation by seeding is not possible for sterile hybrid varieties of most lawn grasses). Sod-farms are always drained, fertilized, and irrigated (when necessary) by seepage (Smajstrla et al., 1993). Lawn grasses in Florida consist of the quasi-evergreen St. Augustine-grass (*Stenotaphrum secundatum* Walt.), centipedegrass, bahiagrass, and zoysiagrass (*Zoysia tenuifolia* L.); grass for golf-courses and athletic fields is Bermudagrass (McCarty and Cisar, 1990). The primary sod-farm grasses are St. Augustine-grass, bahiagrass, and centipedegrass; Bermudagrass and zoysiagrass are grown in smaller amounts (McCarty and Cisar, 1990).

Pasture/sod has been cultivated in Florida mainly since the early 1900s.

Citrus orchard. Citrus orchard consists of kilometer-scale groves of subtropical citrus trees; it is practiced in north and south Florida, primarily on flatwoods sand, deep sand, and upland loamy sand. It is drained on flatwoods sand, and irrigated on deep sand and upland loamy sand. Irrigation is (currently) provided mainly by micro-irrigation, in the form of stationary low flow-rate emitters (Smajstrla et al., 1993). Citrus trees grown in Florida at kilometer scale include orange (*Citrus sinensis* L.), grapefruit (*Citrus paradisi* Macf.), tangerine (*Citrus reticulata* Blanco), and various hybrids of these, such as tangelo, tangor, and Persian-lime (Ziegler and Wolfe, 1961).

Citrus orchard has been cultivated in Florida since colonial times. It was well-established commercially in northeast Florida by 1763, but a succession of severe freezes in 1894, 1895, and 1899 wiped out these early groves (Ziegler and Wolfe, 1961); the land-cover of this former grove area now consists of mixed agriculture and suburb. The center of commercial citrus orchard agriculture moved to central Florida, where it had been expanding since the 1870s, and the previous levels of production were resumed there by 1910 (FDA, 1954). Heavy damage from a succession of freezes in the mid 1980s destroyed many of the northmost central Florida citrus orchards on the central ridge (between Okahumpka and Orlando); these were not replanted--most new groves have since been

planted further south in the Indian River and Allapattah Flats areas. The only variety of citrus grown commercially before 1900 was orange (FDA, 1954). Commercial grapefruit orchards began about 1910; later additions included tangerine and various hybrids (mandarin, tangelo, etc.). The kilometer-scale, conventional form of citrus orchard consists of the subtropical trees described above; the smaller-scale groves of the tropical key-lime (Citrus aurantifolia Swingle) in extreme south Florida are included in the orchard component of the mixed agriculture land-cover category.

Mixed agriculture. Mixed agriculture consists of a kilometer-scale mixture of several agricultural types. These can include row-crops, pasture, field-crops, hayfields, orchards, woodlots, and (on flatwoods sand) ponds. At any given season, some fields will be vegetated and others bare, and the seasonal pattern will change for a given field each year due to crop rotation. Mixed agriculture has been practiced in north and panhandle Florida since colonial times; it has been practiced in south Florida mainly since the late 1800s.

Row-crops, pasture, and citrus orchard have been described previously. Field-crops are seasonal crops on tilled land; the crops provide full coverage of the soil early in the season. They consist of corn (Zea mays L.), sugarcane (Saccharum officinarum L.), wheat (Triticum spp.), triticale (Triticum spp. x Secale spp.), grain-sorghum (Sorghum bicolor L.), rice (Oryza sativa L.), oats (Avena fatua L.), pearl-

millet (Pennisetum americanum L.), and some foxtail-millet (Setaria italica L.). Irrigation is performed by seepage, sprinkler gun, or center-pivot (travelling low-pressure sprinkler), depending on local soil conditions and groundwater supplies (Smajstrla et al., 1993). Sugarcane and rice are grown primarily on organic soil in the EAA, while corn is grown on both organic and sandy/loamy soil types throughout the state. Wheat, triticale, oats, and millet are grown on loamy soil types in the north and panhandle. Corn is grown in spring and fall; grain-sorghum and millet are grown in summer; wheat, triticale, and oats are grown in winter; sugarcane and rice have an extended growing season (more than one year for sugarcane) with primary and secondary (ratoon) harvests.

Hayfields consist of fall and winter forage and silage crops of winter-ryegrass (Lolium perenne L.), alfalfa (Medicago sativa L.), white-clover (Trifolium repens L.), and red-clover (Trifolium pratense L.), and summer forage crops of cowpea (Vigna spp.) and perennial-peanut (Arachis glabrata L.). Irrigation is performed by seepage, sprinkler gun, center-pivot, or not at all, depending on local soil conditions and groundwater supplies (Smajstrla et al., 1993). Hayfields are located primarily in the north and panhandle.

In north Florida, commercial orchards other than conventional citrus include smaller-scale groves of the evergreen kumquat (Fortunella spp.) and the deciduous pecan (Carya illinoensis Wang.), chestnut (Castanea spp.), peach (Prunus persica L.), apple (Malus spp.), and oriental

persimmon (Diospyros kaki L.), as well as vineyards of bunch grape (Vitis aestivalis Michx.) and muscadine grape (Vitis rotundifolia Michx.), and berry farms of the perennial blueberry (Vaccineum corymbosum L.) and blackberry (Rubus argutus Link) bushes. Irrigation is performed mainly by micro-irrigation or not at all, except for blueberries, which are irrigated mainly by sprinkler gun (Smajstrla et al., 1993). A relatively small amount of central Florida tree-related agriculture involves commercial production of leatherleaf fern (Rumohra adiantiformis Forst) and ornamental asparagus (Asparagus springeri Regel, Asparagus setaceus Regel) on deep sand for the florist trade. About 40% of these micro-irrigated ferneries operate beneath a closed canopy of native live oak and sand live oak (Henley et al., 1985).

In south Florida, commercial orchards other than conventional citrus include smaller-scale groves of the evergreen mango (Mangifera indica L.), avocado (Persea americana L.), carambola (Averrhoa carambola L.), white-sapote (Casimiroa edulis L.), papaya (Carica papaya L.), guava (Psidium guajava L.), canistel (Pouteria campechiana L.), lychee (Litchi chinensis L.), sapodilla (Manilkara zapota L.), key-lime, and specialty-bananas (Musa spp.), as well as the deciduous sweetsop (Annona squamosa L.), atemoya (Annona squamosa x cherimola), and mamey-sapote (Pouteria sapota L). Irrigation is performed mainly by micro-irrigation (Smajstrla et al., 1993).

Woodlots consist of small (typically 10 to 40 acre) stands of pine or hardwood trees; narrow bands of pine, red-cedar, Australian-pine (Casuarina equisetifolia L.)--in south, and hardwoods along fence-lines and windbreaks; and narrow bands of natural swamp forest along creeks, rivers, and ponds. Woodlots are seldom deliberately irrigated.

In flatwoods and wetter rockland soil areas, mixed agriculture usually contains the additional component of small ponds. Some of these are holding ponds--artificial reservoirs storing the water necessary for seasonal irrigation. Others are aquacultural ponds for commercial growing of ornamental fish--and to a lesser areal extent--aquarium plants, alligators, catfish, crawfish, game fish (for stocking), freshwater prawns, eels, and tilapia (FASS, 1990).

## Urban/Industrial Land-Cover

Many different urban/industrial land-cover types exist in Florida. The population of the state has increased from about 141,000 (an early census figure excluding American Indians) in 1860 (Blakey, 1973; Hoffman, 1993), to a total of 12,937,926 in 1990 (Hoffman, 1993). It exceeded 1,000,000 by 1930, and had its fastest rate of 20th-century increase during the period from 1950 to 1960 (USBOC, 1979; Hoffman, 1993). Prior to 1900, only about a quarter of the state population was located in the south (Blakey, 1973). This research included eight general urban/industrial types which occur at meso-scale (Figure 18). These consist of suburb, platted suburb, finger-

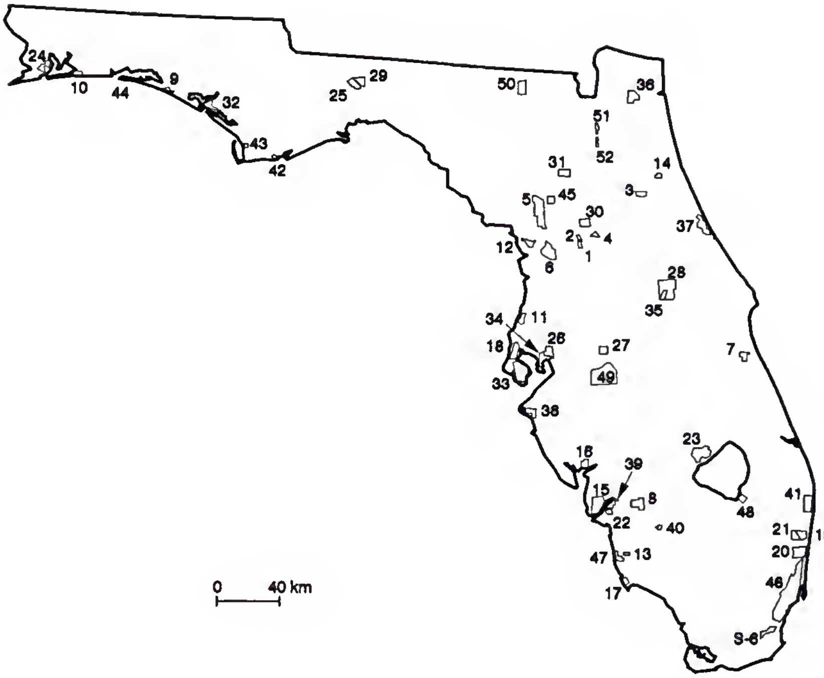


Figure 18. Urban/industrial land-cover polygons (see Appendix C for details).

canal suburb, golf-course suburb, Indian reservation, urban center, phosphate mine, and titanium mine.

Suburb. Suburb consists of urbanized areas that are primarily low-density residential in character. It includes a kilometer-scale mixture of houses, pavement, lawns, and trees. Lawns include the quasi-evergreen grasses St. Augustine-grass, bahiagrass, centipedegrass, and Bermudagrass; in winter, lawns are often sown with winter-ryegrass. Lawns are usually irrigated at night. Ornamental trees include a mixture of both deciduous and evergreen trees whether in north or south Florida (Meerow and Black, 1988b).

Suburbs have been constructed in Florida mainly since the 1950s. They have been built on almost every soil type. Concern for the microclimate effects of variation in the fraction of suburban land-cover components has appeared in recent times, mainly for purposes of energy conservation (Meerow and Black, 1988a). Due to restriction of lateral air movement, the placement of tree windbreaks and walls can lead to higher daytime and nighttime temperatures in enclosed lawn areas than would be the case with no obstacles at all (Meerow and Black, 1988a).

Platted suburb. Platted suburb consists of areas that have streets and cleared (to some degree) lots, but few houses. It includes a kilometer-scale mixture of clearings, pavement, lawns, and trees. Usually it is a transitional type, but in some places it lasts for years.

Finger-canal suburb. Finger-canal suburb consists of urbanized coastal areas that are residential in character, with a network of finger canals constructed to allow boat access from each house to the sea. It includes a kilometer-scale mixture of houses, pavement, lawns, trees, and seawater.

Golf-course suburb. Golf-course suburb consists of urbanized areas that are both residential and recreational in character, with numerous golf courses. It includes a kilometer-scale mixture of houses, pavement, lawns, trees, and golf-courses.

Grass species required for golf-courses include the permanent Bermudagrass, which is over-seeded from fall to spring with creeping bentgrass (*Agrostis palustris* Huds.), roughstalk bluegrass (*Poa trivialis* L.), and winter-ryegrass (McCarty et al., 1990, 1993). The placement of the relatively few trees and shrubs on golf-courses tends to prevent lateral air movement, leading to higher temperatures than for bare sod alone (Meerow and Black, 1988a; McCarty et al., 1990). This is a matter of concern in springtime, because surface temperatures (top of soil) above 80 °F cause decline of bentgrass, and surface temperatures above 100 °F will kill it (McCarty et al., 1990).

Indian reservation. Indian reservation consists of areas under traditional-style residential use by American Indians. It includes a kilometer-scale mixture of trees, pasture/range, and houses--many with traditional palm-thatched roofs. The trees are primarily live oak and cabbage palm. Similar

communities have existed in Florida since pre-Columbian times (Goggin, 1975).

Urban center. Urban center consists of areas having a strongly urbanized character, with high-density residential areas, transportation centers, and business/manufacturing districts. It includes a kilometer-scale mixture of pavement, buildings, and a variable fraction of trees. Urban centers have been built in Florida since 1565 (Ziegler and Wolfe, 1961); most of their expansion has occured since the 1800s (Hoffman, 1993). Only since the early 1900s has it been possible to build urban centers on organic soil in the EAA (Izuno, 1989).

Phosphate mine. Phosphate mine consists of areas (primarily on flatwoods sand) strip-mined for phosphate. It includes a kilometer-scale mixture of cleared land, mounds of sand from overburden and tailings, and settling "slime" ponds (Hochmuth et al., 1987). The older ponds contain a settled phosphatic clay, and are generally covered either by de-watering cover crops (primarily alfalfa) or by wet-prairie vegetation (primarily cattail, saltbush, and bluestem-grass). Many phosphate deposits have been re-worked as new processing techniques have been developed.

Phosphate has been mined commercially from tricalcium phosphate ore in Florida since the 1890s (Blakey, 1973). Large-scale mining involving on-site processing of phosphoric acid and superphosphate began in 1948 in the present centers of the industry in Florida, which are the pebble-phosphate ore

areas of north (Hamilton County) and west-central ("Bone Valley" district of Polk and Hillsborough Counties) Florida (Blakey, 1973; Yon and Oglesby, 1975).

There has been some effort in recent decades to reclaim mined land for agriculture and naturalization (Yon and Oglesby, 1975). The sand mounds are readily reclaimed for either purpose, and for agriculture the uses have included pasture and citrus orchard (Blakey, 1973). Reclamation of the settling ponds has been more problematic; although use for row-crop, field-crop, hayfield, sod-farm, and ornamental-tree nursery agricultural types has been investigated, concerns involving vegetation uptake of radionuclides and especially molybdenum from the phosphatic clay have yet to be answered fully (Shibles and Stricker, 1990). Naturalization of settling ponds has included marsh reclamation (Blakey, 1973).

Titanium mine. Titanium mine consists of areas (primarily on deep sand) strip-mined for titanium. It includes cleared land, mounds of sand from tailings, and ponds (not for settling). Titanium has been mined commercially from ilmenite ore in northeast Florida since 1916 (Martens, 1928). Many former titanium mines near Jacksonville (Martens, 1928; Yon and Oglesby, 1975) are now under urban land-cover. The present center of the industry in Florida is the Trail Ridge area in the northeast (Clay County) (Force, 1976). Types of commercial mining other than titanium and phosphate exist in Florida--limestone quarrying, clay mining, peat mining, and

sand/gravel mining, but these operate at a much smaller spatial scale (Yon and Oglesby, 1975).

## Special Land-Cover Conditions

Several special land cover conditions have been present in Florida during the preparation of this research. These have included both natural and artificial events. Natural conditions included drought, freezes, and a hurricane. Artificial conditions included wetland disturbance and exotic forest invasion.

It should be noted in passing that the winter blizzard or Century Storm of 13 March 1993, while costly in human life and property damage from the Florida Big Bend northwards to most of the southeastern United States, left little lasting kilometer-scale impact in north Florida. This was because natural and agricultural areas were quickly re-vegetated (the results of such cold two weeks later might have been more lasting in the natural areas) after the brief period of damaging cold temperatures, and because most of the north Florida wind damage was in the form of highly localized tornado touchdowns. In non-touchdown areas, only one component (laurel oak) of the diverse local forest and urban tree community experienced a high rate of toppling.

Drought effect on swamp. Bay swamp and mixed swamp within portions of the Suwannee river basin (Figure 16) were under a drought condition during the span of AVHRR imagery used in this research (winter of 1989 to spring of 1993). The

HCMM data used in this research pre-dated this drought condition (1979). These areas were compared respectively to normal bay swamp and mixed swamp. The droughty mixed swamp experienced wildfire two months (June 1993) after the spring 1993 image was taken.

Freeze damage effect on citrus orchard. An area of north Florida citrus orchard on deep sand was destroyed by freeze damage during the winters of 1983 and 1985 (Figure 17). This area is now under an altered condition consisting of a meso-scale mixture of (predominantly) abandoned land (wild grasses and scrubby rootstock regrowth), with some sand pine plantations and a few commercial vineyards of the deciduous bunch and muscadine grapes (Halbrook, 1989). It was compared to areas of normal citrus orchard on deep sand. The AVHRR data used in this research post-dated this damaged condition; the HCMM data pre-dated it.

Hurricane damage effect on urban center. The southern tip of Florida experienced damage from Hurricane Andrew on 24-25 August 1992. This hurricane lacked a major saltwater storm surge; its effects were principally due to strong winds. While natural and agricultural areas in the hurricane path were quickly re-vegetated, the urban area took far longer to recover. In the natural areas, forest trees were largely defoliated, and some were toppled, but standing trees quickly refoliated and subtropical growth quickly refilled any temporary clearings (coastal mangrove swamps were an exception); marsh, by its nature, suffered negligible lasting

wind-damage. In agricultural areas, most winter-vegetable crops were not yet planted, although some laid-down plastic mulch was obliterated; tropical fruit trees were largely defoliated, and some were toppled, but standing trees quickly refoliated and many toppled trees were righted; greenhouses and shadehouses were obliterated. In urban areas, buildings were largely obliterated and the trees defoliated and (especially _Ficus_ spp.) toppled, but toppled palms were quickly righted, and lawns/shrubbery suffered few lasting effects.

A heavily damaged urban center on sandy rockland (Homestead/Leisure City) which was destroyed by the hurricane (Figure 18) was compared to a normal urban center on sandy rockland (Miami/Ft. Lauderdale). This damaged area consisted of a kilometer-scale mixture of streets and lawns, with few buildings. The spring AVHRR images dating from four months (December 1992) and eight months (April 1993) after the hurricane were used to investigate any seasonal components of surface temperature change. The winter AVHRR images used in this research, as well as the HCMM images, pre-dated the hurricane damage.

_Wetland disturbance effects._ Two south Florida wetland types were studied for the effects of artificial disturbance. These included dwarf-cypress swamp and marsh.

An area of south Florida dwarf-cypress swamp has been disturbed (since the 1950s) by the construction of a network of roads for a large planned suburb (later suspended) on the

marly rockland. This area (Figure 16) was compared to normal dwarf-cypress swamp.

Two areas of marsh in south Florida are located within the EAA water-control system. The system of drainage canals has existed in this part of the EAA since the 1920s (Izuno, 1989). The adjoining Holey Land/Rotenberger tracts, under state management as Wildlife Management Areas, comprise the less impacted of the two studied marsh areas. Water Conservation Area 1 (WCA-1), under federal management as the Loxahatchee National Wildlife Refuge, has been heavily disturbed by altered hydrology related to back-pumping of EAA drainage water (Izuno, 1989; Abtew and Khanal, 1994; Rutchey and Vilcheck, 1994). The two disturbed marsh areas (Figure 16) were compared to normal marsh. Meso-scale disturbance of wetlands by hydrologic alteration has also been of concern in western Europe (Stein et al., 1991).

Exotic forest invasion. An area of exotic forest was compared to normal flatwoods forest. The West Green Acres exotic forest area (Figure 16) consists of former flatwoods forest (with cypress domes) and abandoned agricultural land on flatwoods sand, which has been completely overtaken by exotic pest trees. The upper story includes the evergreen punk-tree (Melaleuca quinquenervia Cav.) and Australian-pine (an angiosperm that is not related to true pines). Understory consists almost entirely of Brazilian pepper-tree, which is not related to the cultivated red pepper (Capsicum spp.) or black pepper (Piper spp.) plants.

These trees are all very fast-growing, exotic species which have become naturalized pests in south Florida since the 1950s (Barrett, 1956; Elias, 1980; EPPC, 1990; FDNR, 1990; Butts et al., 1991). The punk-tree was originally introduced in the early 1900s in order to drain wetlands and also for ornamental purposes (Barrett, 1956; EPPC, 1990); it is now banned from deliberate planting in Florida. Australian-pine was introduced in the 1890s as a timber and windbreak tree, even though it topples easily (Barrett, 1956; Elias, 1980; EPPC, 1990). Brazilian pepper-tree was introduced in the 1890s as an ornamental and windbreak tree (Barrett, 1956; EPPC, 1990).

All three of these exotic pest-trees recover quickly from mechanical and fire damage; punk-tree is not only fireproof (flame-retardant bark, hence the name "punk"), it actually releases seeds in response to fire (much like the native fire-dependent pines) (EPPC, 1990). These species all tolerate high and fluctuating water tables, and to a varying extent, salinity. The leaf-litter of Australian-pine and Brazilian pepper-tree contains substances which suppress the growth of other vegetation species; Australian-pine has the additional advantage of nitrogen-fixing microbes within its roots (EPPC, 1990). Punk-tree and Australian-pine often form pure, even-aged stands. An area of approximately 3 million acres in south Florida has become exotic-invaded forest; only a lack of freeze-tolerance keeps exotic forest from extending its range northward (EPPC, 1990). Mechanical removal (cutting and

pulling), followed by defoliant chemical application, is the present countermeasure employed by various agencies; biological countermeasures are still in the research stage (EPPC, 1990).

Other areas of exotic forest in extreme south Florida include many additional tree species (Meerow and Black, 1988b; EPPC, 1990), such as the Asiatic colubrina (Colubrina asiatica L.), jambolan (Syzygium cumini L.), ear-tree (Enterolobium cyclocarpum L.), toog (Bischoffia javanica L.), Eucalyptus (Eucalyptus spp.), weeping fig (Ficus benjamina L.), Cuban-laurel fig (Ficus retusa L.), lofty fig (Ficus altissima L.), canistel, guava, strawberry guava (Psidium cattleianum L.), papaya, rose-apple (Syzigium jambos L.), and sandbox-tree (Hura crepitans L.). Asiatic colubrina was carried from the Caribbean Islands to Florida by seeds floating on the sea (EPPC, 1990). Several Eucalyptus species were introduced as timber trees, and are still cultivated as such in commercial plantations (FDF, 1988; USDA, 1989). Jambolan was introduced as a fruit and ornamental tree (Barrett, 1956). The various exotic figs, ear-tree, and toog were introduced as ornamentals (Meerow and Black, 1988b). Canistel, guava, strawberry guava, papaya, and rose-apple were introduced as fruit trees; the guava and papaya are still cultivated as such in commercial groves. Sandbox-tree, a south American timber species introduced as a curiosity, has been banned from deliberate planting in Dade County, due to the hazard associated with its explosive pods of sharp poisonous seeds (Barrett, 1956).

Exotic vegetation invasion is a problem that is not unique to Florida; it occurs anywhere that introduced exotic species, in the absence of natural controls, aggressively displace native species. North American examples include kudzu vine (*Pueraria lobata* Willd.) and Chinese privet (*Ligustrum sinense* Lour.) in the southern United States, multiflora rose (*Rosa multiflora* Thunb.) in the midwestern United States, and tamarisk (*Tamarix gallica* L.) and tumbleweed (*Salsola kali tenuifolia* L.) in the western United States. International examples include prickly-pear cactus (*Opuntia* spp.) in Australia, blackberry (*Rubus* spp.) in New Zealand, cinnamon (*Cinnamomum zeylanicum* L.) in southeast Asia, and cardoon (*Cynara cardunculus* L.) in the South American pampas (Martin, 1972; Akin, 1991).

# RESULTS AND DISCUSSION

Analyses of AVHRR-based afternoon surface temperature (AST), night surface temperature (NST), and diurnal surface temperature variation (DSTV) patterns were performed using the GIS both across and within the three macro-climate zones--Panhandle (P), North (N), and South (S). All temperatures reported here are in degrees C, rounded to the nearest 0.2 C. Values of differences in means below 0.2 C were considered insignificant (below precision of temperature data in the GIS); those below 1.0 C were considered insubstantial (less than the uncertainty of surface temperature due to emissivity knowledge to the nearest 0.01).

## Analyses Across Macroclimate Zones

Across-zone analyses were performed for the natural land-cover types to assess the macroclimate component of across-zone bias. Results are shown in Tables 1, 2, 3, 4, 5, and 6 for spring AST, spring NST, spring DSTV, winter AST, winter NST, and winter DSTV. It should be noted that not all natural land-cover types were present in all three zones. Macroclimate influence produced substantial differences in these six surface temperature patterns between the three Florida macroclimate zones for most of the natural land-cover types.

Table 1. Spring afternoon surface temperature across-zone differences among natural land-cover types.

| Natural cover type | Zones crossed | | | Difference in AST means (C)[a] |
|---|---|---|---|---|
| Scrub, evergreen | N | to | S | 1.6** |
| Scrub, mixed | P | to | N | 1.2** |
| Upland mixed forest | P | to | N | -0.4** |
| Flatwoods forest | P | to | N | 0.4** |
| | N | to | S | 1.0** |
| | P | to | S | 1.4** |
| Rockland hammock | N | to | S | 3.8** |
| Coastal hammock | P | to | N | 1.0** |
| | N | to | S | 0.8** |
| | P | to | S | 1.8** |
| Hardwood swamp, evergreen | N | to | S | -0.4** |
| Hardwood swamp, deciduous | P | to | N | 3.0** |
| Cypress swamp | N | to | S | -0.6** |
| Bay swamp | P | to | N | 0.0 |
| Mixed swamp | N | to | S | 0.0 |

Table 1--continued.

| Natural cover type | Zones crossed | | | Difference in AST means (C)[a] |
|---|---|---|---|---|
| Marsh | P | to | N | 0.2 |
| | N | to | S | 0.2** |
| | P | to | S | 0.6** |
| Saltmarsh | P | to | N | 0.4** |
| | N | to | S | 4.6** |
| | P | to | S | 4.8** |

[a] difference is positive if mean of zone at right is larger than mean of zone at left.

* significant at $\alpha = 0.05$.

** significant at $\alpha = 0.01$.

Table 2. Spring nighttime surface temperature across-zone differences among natural land-cover types.

| Natural cover type | Zones crossed | | | Difference in NST means (C)[a] |
|---|---|---|---|---|
| Scrub, evergreen | N | to | S | 0.0 |
| Scrub, mixed | P | to | N | 0.2** |
| Upland mixed forest | P | to | N | 0.4** |
| Flatwoods forest | P | to | N | -0.4** |
| | N | to | S | 4.2** |
| | P | to | S | 3.6** |
| Rockland hammock | N | to | S | -0.2* |
| Coastal hammock | P | to | N | -1.6** |
| | N | to | S | 2.0** |
| | P | to | S | 0.4* |
| Hardwood swamp, evergreen | N | to | S | 2.2** |
| Hardwood swamp, deciduous | P | to | N | -1.8** |
| Cypress swamp | N | to | S | 1.8** |
| Bay swamp | P | to | N | 2.6** |
| Mixed swamp | N | to | S | 1.0** |

Table 2--continued.

| Natural cover type | Zones crossed | | | Difference in NST means (C)[a] |
|---|---|---|---|---|
| Marsh | P | to | N | -0.6 |
| | N | to | S | 4.0** |
| | P | to | S | 3.4** |
| Saltmarsh | P | to | N | 0.2 |
| | N | to | S | 0.8** |
| | P | to | S | 1.0** |

[a] difference is positive if mean of zone at right is larger than mean of zone at left.

* significant at $\alpha = 0.05$.

** significant at $\alpha = 0.01$.

Table 3. Spring diurnal surface temperature variation across-zone differences among natural land-cover types.

| Natural cover type | Zones crossed | | | Difference in DSTV means (C)[a] |
|---|---|---|---|---|
| Scrub, evergreen | N | to | S | 1.8** |
| Scrub, mixed | P | to | N | 0.8** |
| Upland mixed forest | P | to | N | -0.8** |
| Flatwoods forest | P | to | N | 1.0** |
| | N | to | S | -3.2** |
| | P | to | S | -2.2** |
| Rockland hammock | N | to | S | 3.8** |
| Coastal hammock | P | to | N | 2.6** |
| | N | to | S | -1.2** |
| | P | to | S | 1.2** |
| Hardwood swamp, evergreen | N | to | S | -2.6** |
| Hardwood swamp, deciduous | P | to | N | 4.8** |
| Cypress swamp | N | to | S | -2.4** |
| Bay swamp | P | to | N | -2.6** |
| Mixed swamp | N | to | S | -1.0** |

Table 3--continued.

| Natural cover type | Zones crossed | | | Difference in DSTV means (C)[a] |
|---|---|---|---|---|
| Marsh | P | to | N | 0.8 |
| | N | to | S | -3.6** |
| | P | to | S | -3.0** |
| Saltmarsh | P | to | N | 0.2 |
| | N | to | S | 3.6** |
| | P | to | S | 3.8** |

[a] difference is positive if mean of zone at right is larger than mean of zone at left.

* significant at $\alpha = 0.05$.

** significant at $\alpha = 0.01$.

Table 4. Winter afternoon surface temperature across-zone differences among natural land-cover types.

| Natural cover type | Zones crossed | | | Difference in AST means (C)[a] |
|---|---|---|---|---|
| Scrub, evergreen | N | to | S | 0.8** |
| Scrub, mixed | P | to | N | 0.8** |
| Upland mixed forest | P | to | N | 0.2** |
| Flatwoods forest | P | to | N | -0.4** |
| Coastal hammock | P | to | N | 0.8** |
| Hardwood swamp, deciduous | P | to | N | 2.2** |
| Bay swamp | P | to | N | 1.2** |
| Marsh | P | to | N | 1.6** |
| | N | to | S | 3.2** |
| Saltmarsh | P | to | N | 0.6** |

[a] difference is positive if mean of zone at right is larger than mean of zone at left. Comparisons of zones P and N were performed using 1992 image data; those of zones N and S were performed using 1989 image data.

* significant at $\alpha = 0.05$.

** significant at $\alpha = 0.01$.

Table 5. Winter nighttime surface temperature across-zone differences among natural land-cover types.

| Natural cover type | Zones crossed | | | Difference in NST means (C)[a] |
|---|---|---|---|---|
| Scrub, evergreen | N | to | S | 0.0 |
| Scrub, mixed | P | to | N | 3.6** |
| Upland mixed forest | P | to | N | 1.4** |
| Flatwoods forest | P | to | N | -0.4** |
| Coastal hammock | P | to | N | -2.2** |
| Hardwood swamp, deciduous | P | to | N | -0.6** |
| Bay swamp | P | to | N | 2.8** |
| Marsh | P | to | N | 2.8** |
| | N | to | S | 5.6** |
| Saltmarsh | P | to | N | 1.2** |

[a] difference is positive if mean of zone at right is larger than mean of zone at left. Comparisons of zones P and N were performed using 1992 image data; those of zones N and S were performed using 1989 image data.

* significant at $\alpha = 0.05$.

** significant at $\alpha = 0.01$.

Table 6. Winter diurnal surface temperature variation across-zone differences among natural land-cover types.

| Natural cover type | Zones crossed | | | Difference in DSTV means (C)[a] |
|---|---|---|---|---|
| Scrub, evergreen | N | to | S | 1.0** |
| Scrub, mixed | P | to | N | -2.8** |
| Upland mixed forest | P | to | N | -1.0** |
| Flatwoods forest | P | to | N | 0.0 |
| Coastal hammock | P | to | N | 3.2** |
| Hardwood swamp, deciduous | P | to | N | 2.8** |
| Bay swamp | P | to | N | -1.6** |
| Marsh | P | to | N | -1.2** |
| | N | to | S | -2.4** |
| Saltmarsh | P | to | N | -0.6** |

[a] difference is positive if mean of zone at right is larger than mean of zone at left. Comparisons of zones P and N were performed using 1992 image data; those of zones N and S were performed using 1989 image data.

* significant at $\alpha = 0.05$.

** significant at $\alpha = 0.01$.

The AST and NST values were generally higher with distance south in both spring and winter, as expected. The largest across-zone differences were between zones P and S, as expected. AST across-zone differences ranged to 3.2 C in winter, and to 4.8 C in spring. NST across-zone differences ranged to 5.6 C in winter, and to 4.2 C in spring.

The DSTV across-zone differences were less easy to predict, since they serve as an indication of differences in relative moisture conditions for a given natural land-cover from zone to zone. DSTV across-zone differences ranged to 3.2 C in winter, and to 4.8 C in spring.

These results indicate that any comparisons of surface temperature pattern differences across macroclimate zones would have to be made with due consideration of the macroclimate component of zone bias. For example, the thermal pattern of a flatwoods forest in zone P cannot be compared directly to that of a flatwoods forest in zone S, because of differences in soil moisture (from differences in antecedent precipitation) and in near-surface air temperature, both of which are forcing factors for surface temperature (see equation 2). Agricultural and urban land-cover types were not evaluated for across-zone differences, because of their artificial control of soil moisture levels through drainage and irrigation. However, they can be reasonably assumed to have across-zone differences for a given land-cover and soil type. These across-zone differences would be due to temporal differences in the crop growing seasons for agricultural land-

cover, and in the irrigation of lawns and ornamental vegetation for urban land-cover.

## Analyses Within Macroclimate Zones

Within-zone analyses were performed to assess the surface temperature pattern differences between different combinations of land-cover and soil type, and the surface temperature effects of land-cover changes and special conditions. Results are discussed below.

### Spring Afternoon Natural Land-Cover Thermal Patterns

Zone P. Within zone P in spring, eight natural land cover types were present. Listed in order of decreasing mean AST (C), these included mixed scrub (27.4), upland mixed forest (26.6), flatwoods forest (25.8), marsh (25.6), bay swamp (24.0), deciduous hardwood swamp (23.2), coastal hammock (22.8), and saltmarsh (22.8). Differences in mean AST among zone P natural land cover types are given in Table 7; most were significant, and many were substantial. The highest difference (4.6 C) was between mixed scrub and saltmarsh. The overall trend was a higher AST for the drier natural land-cover types (mixed scrub, upland mixed forest), and lower AST for the wetter types (marshes and swamps).

Zone N. Within zone N in spring, thirteen natural land cover types were present. Listed in order of decreasing mean AST (C), these included mixed scrub (28.4), evergreen scrub (27.8), flatwoods forest (26.4), upland mixed forest (26.4),

Table 7. Spring afternoon surface temperature differences among natural land-cover types in panhandle zone.

| Natural cover type | Difference in AST (C) mean for natural cover type[a] | | | | | | |
|---|---|---|---|---|---|---|---|
| | SCM | FMX | FLW | MRF | SBY | SHD | HCO |
| FMX | 0.6** | | | | | | |
| FLW | 1.4** | 0.8** | | | | | |
| MRF | 1.6** | 1.0** | 0.2 | | | | |
| SBY | 3.4** | 2.8** | 2.0** | 1.6** | | | |
| SHD | 4.0** | 3.4** | 2.6** | 2.4** | 0.6** | | |
| HCO | 4.4** | 3.8** | 3.0** | 2.8** | 1.2** | 0.4** | |
| MRS | 4.6** | 4.0** | 3.2** | 2.8** | 1.2** | 0.6** | 0.0 |

[a] Positive number indicates increase in spring afternoon surface temperature mean for the natural cover type compared to that of the left-column natural cover type. The natural cover types are denoted as follows: SCM = mixed scrub, FMX = upland mixed forest, FLW = flatwoods forest, MRF = marsh, SBY = bay swamp, SHD = deciduous hardwood swamp, HCO = coastal hammock, and MRS = saltmarsh. These natural cover types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

deciduous hardwood swamp (26.2), cypress swamp (26.2), mixed swamp (25.8), marsh (25.8), evergreen hardwood swamp (25.4), rockland hammock (24.0), bay swamp (23.8), coastal hammock (23.8), and saltmarsh (23.0). Differences in mean AST among zone N natural land cover types are given in Table 8; most were significant, and many were substantial. Among these natural land cover types, the highest difference (5.4 C) in AST was between mixed scrub and saltmarsh. The overall trend was a higher AST for the drier natural land-cover types (mixed scrub, evergreen scrub), and lower AST for the wetter types (marshes and swamps). Differences between evergreen and deciduous subtypes of scrub and hardwood swamp were significant, but not substantial--as expected from a spring date (deciduous subtypes in full foliage).

Zone S. Within zone S in spring, fourteen natural land cover types were present. Listed in order of decreasing mean AST (C), these included evergreen scrub (29.6), wet-prairie (28.4), rockland hammock (27.6), brackish marsh (27.6), flatwoods forest (27.4), dwarf cypress swamp (26.6), deciduous shrubby marsh (26.4), marsh (26.2), mixed swamp (25.8), cypress swamp (25.6), evergreen shrubby marsh (25.6), mangrove swamp (25.4), evergreen hardwood swamp (25.0), and coastal hammock (24.6). Differences in mean AST among zone S natural land cover types are given in Table 9; most were significant, and many were substantial. Among these natural land cover types, the highest difference (5.0 C) in AST was between evergreen scrub and coastal hammock. The overall trend was a

Table 8. Spring afternoon surface temperature differences among natural land-cover types in north zone.

| Natural cover type | Difference in AST (C) mean for natural cover type[a] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SCM | SCE | FLW | FMX | SHD | SCY | SMX | MRF | SHE | HRO | SBY | HCO |
| SCE | 0.6$^{**}$ | | | | | | | | | | | |
| FLW | 2.2$^{**}$ | 1.4$^{**}$ | | | | | | | | | | |
| FMX | 2.1$^{**}$ | 1.6$^{**}$ | 0.0 | | | | | | | | | |
| SHD | 2.2$^{**}$ | 1.6$^{**}$ | 0.0 | 0.0 | | | | | | | | |
| SCY | 2.4$^{**}$ | 1.8$^{**}$ | 0.2$^{**}$ | 0.2$^{*}$ | 0.2 | | | | | | | |
| SMX | 2.6$^{**}$ | 2.0$^{**}$ | 0.4$^{**}$ | 0.4$^{**}$ | 0.4$^{**}$ | 0.2$^{**}$ | | | | | | |
| MRF | 2.6$^{**}$ | 2.0$^{**}$ | 0.6$^{**}$ | 0.4$^{**}$ | 0.4$^{**}$ | 0.2$^{**}$ | 0.0 | | | | | |
| SHE | 3.0$^{**}$ | 2.4$^{**}$ | 1.0$^{**}$ | 1.0$^{**}$ | 0.8$^{**}$ | 0.8$^{**}$ | 0.4$^{**}$ | 0.4$^{**}$ | | | | |
| HRO | 4.6$^{**}$ | 4.0$^{**}$ | 2.4$^{**}$ | 2.4$^{**}$ | 2.4$^{**}$ | 2.2$^{**}$ | 2.0$^{**}$ | 2.0$^{**}$ | 1.4$^{**}$ | | | |
| SBY | 4.6$^{**}$ | 4.0$^{**}$ | 2.4$^{**}$ | 2.4$^{**}$ | 2.4$^{**}$ | 2.2$^{**}$ | 2.0$^{**}$ | 2.0$^{**}$ | 1.6$^{**}$ | 0.0 | | |
| HCO | 4.6$^{**}$ | 4.0$^{**}$ | 2.6$^{**}$ | 2.6$^{**}$ | 2.4$^{**}$ | 2.4$^{**}$ | 2.0$^{**}$ | 2.0$^{**}$ | 1.6$^{**}$ | 0.2 | 0.0 | |
| MRS | 5.4$^{**}$ | 4.8$^{**}$ | 3.2$^{**}$ | 3.2$^{**}$ | 3.2$^{**}$ | 3.0$^{**}$ | 2.8$^{**}$ | 2.8$^{**}$ | 2.4$^{**}$ | 0.8$^{**}$ | 0.8$^{**}$ | 0.8$^{**}$ |

[a] Positive number indicates increase in spring afternoon surface temperature mean for the natural cover type compared to that of the left-column natural cover type. The natural cover types are denoted as follows: SCM = mixed scrub, SCE = evergreen scrub, FLW = flatwoods forest, FMX = upland mixed forest, SHD = deciduous hardwood swamp, SCY =

Table 8--continued.

cypress swamp, SMX = mixed swamp, MRF = marsh, SHE = evergreen hardwood swamp, HRO = rockland hammock, SBY = bay swamp, HCO = coastal hammock, and MRS = saltmarsh. These natural cover types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Table 9. Spring afternoon surface temperature differences among natural land-cover types in south zone.

| Nat. cov. type | Difference in AST (C) mean for natural cover type[a] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SCE | MRP | HRO | MRS | FLW | SCD | MSD | MRF | SMX | SCY | MSE | SMG | SHE |
| MRP | 1.2** | | | | | | | | | | | | |
| HRO | 1.8** | 0.6** | | | | | | | | | | | |
| MRS | 2.0** | 0.8** | 0.0 | | | | | | | | | | |
| FLW | 2.2** | 1.0** | 0.4* | 0.2** | | | | | | | | | |
| SCD | 3.0** | 1.8** | 1.2** | 1.2** | 0.8** | | | | | | | | |
| MSD | 3.0** | 1.8** | 1.2** | 1.2** | 0.8** | 0.0 | | | | | | | |
| MRF | 3.4** | 2.2** | 1.6** | 1.4** | 1.2** | 0.4** | 0.4** | | | | | | |
| SMX | 3.6** | 2.4** | 1.8** | 1.8** | 1.4** | 0.6** | 0.6** | 0.4** | | | | | |
| SCY | 4.0** | 2.8** | 2.0** | 2.0** | 1.8** | 1.0** | 0.8** | 0.6** | 0.2** | | | | |
| MSE | 4.0** | 2.8** | 2.2** | 2.2** | 1.8** | 1.0** | 1.0** | 0.6** | 0.4** | 0.0 | | | |
| SMG | 4.0** | 2.8** | 2.2** | 2.2** | 1.8** | 1.0** | 1.0** | 0.6** | 0.4** | 0.2 | 0.0 | | |
| SHE | 4.4** | 3.2** | 2.6** | 2.6** | 2.2** | 1.4** | 1.4** | 1.0** | 0.8** | 0.4** | 0.4** | 0.4** | |
| HCO | 5.0** | 3.8** | 3.2** | 3.0** | 2.8** | 2.0** | 2.0** | 1.6** | 1.2** | 1.0** | 1.0** | 1.0** | 0.6** |

[a] Positive number indicates increase in spring afternoon surface temperature mean for the natural cover type compared to that of the left-column natural cover type. The natural

Table 9--continued.

cover types are denoted as follows: SCE = evergreen scrub, MRP = wet-prairie, HRO = rockland hammock, MRS = saltmarsh, FLW = flatwoods forest, SCD = dwarf-cypress swamp, MSD = deciduous shrubby marsh, MRF = marsh, SMX = mixed swamp, SCY = cypress swamp, MSE = evergreen shrubby marsh, SMG = mangrove swamp, SHE = evergreen hardwood swamp, and HCO = coastal hammock. These natural cover types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

higher AST for the drier natural land-cover types (evergreen scrub), and lower AST for the wetter types (marshes and swamps). The relatively high AST of wet-prairie and brackish marsh (both on marly rockland soil) reflects their April dry-season hydrology; the marsh subtype (on muck soil) remains wet throughout the year. Deciduous shrubby marsh had higher AST (by 1.0 C) than did evergreen shrubby marsh, which can be attributed to the more open canopy of deciduous shrubby marsh; as will be discussed later, there was no substantial difference in DSTV (relative soil moisture) for these shrubby marsh subtypes. Dwarf-cypress swamp had higher AST than did cypress swamp (by 1.0 C), which can be attributed to the combination of the more open canopy of the dwarf-cypress swamp and its marly rockland soil type; as will be discussed later, there was no substantial difference in DSTV (relative soil moisture) for these swamp subtypes.

## Spring Afternoon Agricultural Land-Cover Thermal Patterns

Zone P. Within zone P, there were two types of agriculture distributed on three soil types. Listed in order of decreasing mean AST (C), these agricultural/soil type combinations included mixed agriculture on deep sand (29.2), mixed agriculture on upland loamy sand (27.8), and pasture/range on flatwoods sand (25.0). Differences in mean AST among zone P agricultural/soil type combinations are given in Table 10; all were both significant and substantial. The highest difference in AST was between mixed agriculture on

Table 10. Spring afternoon surface temperature differences among agricultural land-cover types in panhandle zone.

| Agricultural cover/soil type | Difference in AST (C) mean for agricultural cover/soil type[a] | |
|---|---|---|
| | AXS | AXU |
| AXU | 1.6** | |
| APF | 4.4** | 2.8** |

[a] Positive number indicates increase in spring afternoon surface temperature mean for the agricultural cover/soil type compared to that of the left-column agricultural cover/soil type. The agricultural cover/soil types are denoted as follows: AXS = mixed agriculture on deep sand, AXU = mixed agriculture on upland loamy sand, and APF = pasture/range on flatwoods sand. These cover/soil types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

deep sand and pasture/range on flatwoods sand (4.4 C). Mixed agriculture on deep sand had higher AST (by 1.6 C) than did that on upland loamy sand.

<u>Zone N.</u> Within zone N in spring, there were five agriculture types on up to five different soil types. Listed in order of decreasing mean AST (C), these combinations included mixed agriculture on deep sand (29.4), citrus orchard on deep sand (29.4), citrus orchard on upland loamy sand (29.4), mixed agriculture on upland loamy sand (29.2), row-crops on muck (28.8), mixed agriculture on sandy rockland (28.8), citrus orchard on flatwoods sand (27.8), pasture/sod on muck (27.4), pasture/range on flatwoods sand (27.0), and mixed agriculture on flatwoods sand (26.6). Differences in mean AST among zone N agricultural/soil type combinations are given in Table 11; most were significant, and many were substantial. Among these agricultural land cover types, the highest difference in AST (2.8 C) was between mixed agriculture on deep sand and mixed agriculture on flatwoods sand.

Soil type impacts on agricultural type temperatures were compared. Among the mixed agriculture combinations, that on flatwoods sand had lower AST than that on other soil types. The differences between mixed agriculture on deep sand, upland loamy sand, and sandy rockland were significant, but not substantial. Among the pasture combinations, the difference in AST between pasture/sod on muck and pasture/range on flatwoods sand was significant, but not substantial. Among

Table 11. Spring afternoon surface temperature differences among agricultural land-cover types in north zone.

| Agric. cover/ soil type | Difference in AST (C) mean for agricultural cover/soil type[a] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | AXS | ACS | ACU | AXU | ARM | AXR | ACF | ASM | APF |
| ACS | 0.0 | | | | | | | | |
| ACU | 0.2 | 0.0 | | | | | | | |
| AXU | 0.2** | 0.0 | 0.0 | | | | | | |
| ARM | 0.6** | 0.2* | 0.4* | 0.4 | | | | | |
| AXR | 0.8** | 0.6** | 0.6** | 0.6** | 0.2 | | | | |
| ACF | 1.6** | 1.6** | 1.6** | 1.4** | 1.2** | 1.0** | | | |
| ASM | 2.0** | 1.8** | 1.8** | 1.8** | 1.4** | 1.2** | 0.2** | | |
| APF | 2.4** | 2.2** | 2.2** | 2.2** | 1.8** | 1.6** | 0.6** | 0.4** | |
| AXF | 2.8** | 2.8** | 2.8** | 2.6** | 2.4** | 2.2** | 1.2** | 0.8** | 0.4** |

[a] Positive number indicates increase in spring afternoon surface temperature mean for the agricultural cover/soil type compared to that of the left-column agricultural cover/soil type. The agricultural cover/soil types are denoted as follows: AXS = mixed agriculture on deep sand, ACS = citrus orchard on deep sand, ACU = citrus orchard on upland loamy sand, AXU = mixed agriculture on upland loamy sand, ARM = row-crops on muck, AXR = mixed agriculture on sandy rockland, ACF = citrus orchard on flatwoods sand, ASM = pasture/sod on muck, APF = pasture/range on flatwoods sand, and AXF = mixed agriculture on flatwoods sand. These cover/soil types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

the citrus orchard combinations, that on flatwoods sand had lower AST than did that on either deep sand or upland loamy sand (by 1.6 C in both cases). There was no significant difference in AST between citrus orchard on deep sand and that on upland loamy sand. In zone N in spring, flatwoods sand appears to lower the AST of a given agricultural type, while other soil types appear to have no substantial effect on the AST of mixed agriculture, pasture, or citrus orchard.

Agriculture type impacts on soil type temperatures were compared. Among the deep sand combinations, there was no significant difference in mean AST between mixed agriculture and citrus orchard. Among the upland loamy sand combinations, there was no significant difference between mixed agriculture and citrus orchard. Among the flatwoods sand combinations, citrus orchard had higher AST than did mixed agriculture, while the difference between pasture/range and either citrus orchard or mixed agriculture was significant, but not substantial. Among the muck combinations, row-crops had higher AST (by 1.4) than did pasture/sod. In zone N in spring, differences in AST among certain agricultural types were substantial on flatwoods sand and on muck, but not on deep sand or upland loamy sand.

Zone S. Within zone S, there were five agriculture types on up to six different soil types. Listed in order of decreasing mean AST (C), these combinations included mixed agriculture on muck (32.0), row-crops on flatwoods sand (30.8), mixed agriculture on sandy rockland (30.2), citrus

orchard on deep sand (30.0), pasture/sod on muck (29.0), mixed agriculture on flatwoods sand (28.8), mixed agriculture on marly rockland (28.8), pasture/range on sandy rockland (28.6), citrus orchard on flatwoods sand (28.2), pasture/range on flatwoods sand (27.8), row-crops on marly rockland (27.0), and row-crops on coastal sand (26.0). Differences in mean AST among zone S agricultural/soil type combinations are given in Table 12. Among these agricultural land cover types, the highest difference in AST (6.0 C) was between mixed agriculture on muck and row-crops on coastal sand.

Soil type impacts on agricultural type temperatures were compared. Among the mixed agriculture combinations, the highest difference in AST (3.2 C) was between that on muck and that on marly rockland. There was no significant difference in AST between that on flatwoods sand and that on marly rockland. Differences between other mixed agriculture combinations were both significant and substantial. Among the row-crop combinations, the highest difference in mean AST (4.8 C) was between that on flatwoods sand and that on coastal sand. Differences between other row-crop combinations were both significant and substantial. Among the pasture combinations, the highest difference in AST (1.2 C) was between pasture/sod on muck and pasture/range on flatwoods sand. The differences in AST between pasture/sod on muck and pasture/range on sandy rockland, and between pasture/range on sandy rockland and that on flatwoods sand, were significant, but not substantial. Among the citrus orchard combinations,

Table 12. Spring afternoon surface temperature differences among agricultural land-cover types in south zone.

| Agric. cover/ soil type | Difference in AST (C) mean for agricultural cover/soil type[a] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | AXM | ARF | AXR | ACS | ASM | AXF | AXL | APR | ACF | APF | ARL |
| ARF | $1.2^{**}$ | | | | | | | | | | |
| AXR | $1.6^{**}$ | $0.4^{*}$ | | | | | | | | | |
| ACS | $2.0^{**}$ | $0.8^{**}$ | 0.2 | | | | | | | | |
| ASM | $2.8^{**}$ | $1.8^{**}$ | $1.2^{**}$ | $1.0^{**}$ | | | | | | | |
| AXF | $3.2^{**}$ | $2.0^{**}$ | $1.4^{**}$ | $1.2^{**}$ | 0.2 | | | | | | |
| AXL | $3.2^{**}$ | $2.0^{**}$ | $1.6^{**}$ | $1.4^{**}$ | $0.4^{*}$ | 0.2 | | | | | |
| APR | $3.4^{**}$ | $2.2^{**}$ | $1.6^{**}$ | $1.4^{**}$ | $0.4^{*}$ | 0.2 | 0.0 | | | | |
| ACF | $3.8^{**}$ | $2.6^{**}$ | $2.2^{**}$ | $1.8^{**}$ | $1.0^{**}$ | $0.8^{**}$ | $0.6^{**}$ | $0.6^{*}$ | | | |
| APF | $4.2^{**}$ | $3.0^{**}$ | $2.4^{**}$ | $2.2^{**}$ | $1.2^{**}$ | $1.0^{**}$ | $0.8^{**}$ | $0.8^{**}$ | $0.2^{*}$ | | |
| ARL | $5.0^{**}$ | $3.8^{**}$ | $3.2^{**}$ | $3.0^{**}$ | $2.0^{**}$ | $1.8^{**}$ | $1.6^{**}$ | $1.6^{**}$ | $1.0^{**}$ | $0.8^{**}$ | |
| ARC | $6.0^{**}$ | $4.8^{**}$ | $4.4^{**}$ | $4.0^{**}$ | $3.2^{**}$ | $3.0^{**}$ | $2.8^{**}$ | $2.6^{**}$ | $2.2^{**}$ | $1.8^{**}$ | $1.2^{**}$ |

[a] Positive number indicates increase in spring afternoon surface temperature mean for the agricultural cover/soil type compared to that of the left-column agricultural cover/soil type. The agricultural cover/soil types are denoted as follows: AXM = mixed agriculture on muck, ARF = row-crops on flatwoods sand, AXR = mixed agriculture on sandy rockland, ACS = citrus orchard on deep sand, ASM = pasture/sod on muck, AXF = mixed agriculture on flatwoods sand, AXL = mixed agriculture on marly rockland, APR = pasture/range on

Table 12--continued.

sandy rockland, ACF = citrus orchard on flatwoods sand, APF = pasture/range on flatwoods sand, ARL = row-crops on marly rockland, and ARC = row-crops on coastal sand. These cover/soil types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

that on deep sand had higher AST (by 1.8 C) than did that on flatwoods sand. This was expected, due to the excessively-drained character of the deep sand; as will be discussed later, the DSTV indicated a relatively drier condition for the deep sand citrus orchard. In zone S in spring, the AST of a given agricultural type appears to be increased the most by muck, followed respectively by sandy rockland, deep sand, flatwoods sand, and marly rockland.

Agriculture type impacts on soil type temperatures were compared. Among the muck combinations, mixed agriculture had higher AST (by 2.8 C) than did pasture/sod. This was expected, since mixed agriculture includes more exposed soil, and is maintained under a lower water-table condition than is pasture. Among the sandy rockland combinations, mixed agriculture had higher AST (by 1.6 C) than did pasture/range. This was expected, since mixed agriculture includes more exposed soil, and is maintained under a lower water-table condition than is pasture. Among the marly rockland combinations, mixed agriculture had higher AST (by 1.6 C) than did row-crops. This was expected, since mixed agriculture is maintained under a lower water-table condition than are row-crops. Among the flatwoods sand combinations, row-crops had higher AST (by 2.0 C or more) than did the other agricultural types; this may be attributed to a post-harvest or fallow condition of the row-crops. Mixed agriculture had higher AST (by 1.0 C) than did pasture/range. The differences between mixed agriculture and citrus orchard, and between citrus

orchard and pasture/range, were significant, but not substantial. In zone S in spring, mixed agriculture appeared to increase AST more than did other agricultural types on most soil types.

## Spring Afternoon Urban/Industrial Land-Cover Thermal Patterns

Zone P. Within zone P, there were two types of urban/industrial land cover, distributed on four soil types. Listed in order of decreasing mean AST (C), these included urban center on upland loamy sand (29.2), urban center on deep sand (28.6), urban center on flatwoods sand (26.8), urban center on coastal sand (25.0), and suburb on coastal sand (24.2). Differences in mean AST among zone P urban/industrial cover/soil type combinations are given in Table 13; all were significant, and many were substantial. Urban center on flatwoods sand had lower mean AST than did that on upland loamy sand (by 2.4 C) and that on deep sand (by 1.8 C). The difference between urban center on upland loamy sand and that on deep sand was significant, but not substantial. The difference between urban center on coastal sand and suburb on coastal sand was significant, but not substantial. The highest difference in AST (5.0 C) was between urban center on upland loamy sand and suburb on coastal sand.

Zone N. Within zone N, there were six urban/industrial cover types present on five different soil types. Listed in order of decreasing mean AST (C), the combinations included urban center on deep sand (30.0), urban center on sandy

Table 13. Spring afternoon surface temperature differences among urban/industrial land-cover types in panhandle zone.

| Urban/indus. cover/soil type | Difference in AST (C) mean for urban/industrial cover/soil type[a] | | | |
|---|---|---|---|---|
| | UCU | UCS | UCF | UCC |
| UCS | 0.6** | | | |
| UCF | 2.4** | 1.8** | | |
| UCC | 4.0** | 3.6** | 1.6** | |
| USC | 5.0** | 4.4** | 2.6** | 0.8** |

[a] Positive number indicates increase in spring afternoon surface temperature mean for the urban/industrial cover/soil type compared to that of the left-column urban/industrial cover/soil type. The urban/industrial cover/soil types are denoted as follows: UCU = urban center on upland loamy sand, UCS = urban center on deep sand, UCF = urban center on flatwoods sand, UCC = urban center on coastal sand, and USC = suburb on coastal sand. These cover/soil types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

rockland (29.2), urban center on upland loamy sand (29.2), suburb on deep sand (29.2), urban center on flatwoods sand (28.4), titanium mine on deep sand (27.8), suburb on upland loamy sand (27.8), golf-course suburb on flatwoods sand (27.4), phosphate mine on flatwoods sand (27.4), suburb on flatwoods sand (27.0), suburb on coastal sand (26.6), platted suburb on flatwoods sand (26.4), and suburb on sandy rockland (24.6). Differences in mean AST among zone N urban/industrial cover/soil type combinations are given in Table 14. Among these land cover types, the highest AST difference (5.4 C) was between urban center on deep sand and suburb on sandy rockland.

Soil type impacts on urban/industrial type temperatures were compared. Among the suburb combinations, the highest difference in mean AST (4.4 C) was between suburb on deep sand and that on sandy rockland. The differences between suburb on flatwoods sand and that on either upland loamy sand or coastal sand were significant, but not substantial. The difference between other suburb combinations was both significant and substantial. Among the urban center combinations, urban center on deep sand had higher AST than did that on upland loamy sand (by 1.0 C) and flatwoods sand (by 1.6 C). There was no significant difference in AST between urban center on rockland and that on upland loamy sand. The difference between other urban center combinations was significant, but not substantial. Among the mine combinations, the difference in mean AST between titanium mine on deep sand and phosphate

Table 14. Spring afternoon surface temperature differences among urban/industrial land-cover types in north zone.

| Urban/ indus. cover/ soil type | Difference in AST (C) mean for urban/industrial cover/soil type[a] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | UCS | UCR | UCU | USS | UCF | UMS | USU | UGF | UMF | USF | USC | UPF |
| UCR | 0.8** | | | | | | | | | | | |
| UCU | 1.0** | 0.0 | | | | | | | | | | |
| USS | 1.0** | 0.0 | 0.0 | | | | | | | | | |
| UCF | 1.6** | 0.8** | 0.8** | 0.8** | | | | | | | | |
| UMS | 2.2** | 1.4** | 1.4** | 1.2** | 0.6** | | | | | | | |
| USU | 2.2** | 1.4** | 1.4** | 1.2** | 0.6** | 0.0 | | | | | | |
| UGF | 2.6** | 1.8** | 1.6** | 1.6** | 1.0** | 0.4** | 0.4** | | | | | |
| UMF | 2.6** | 1.8** | 1.8** | 1.8** | 1.0** | 0.4** | 0.4** | 0.0 | | | | |
| USF | 3.0** | 2.2** | 2.2** | 2.0** | 1.4** | 0.8** | 0.8** | 0.4** | 0.4** | | | |
| USC | 3.4** | 2.6** | 2.6** | 2.6** | 1.8** | 1.2** | 1.2** | 0.8** | 0.8** | 0.4** | | |
| UPF | 3.6** | 2.8** | 2.6** | 2.6** | 2.0** | 1.4** | 1.4** | 1.0** | 1.0** | 0.6** | 0.0 | |
| USR | 5.4** | 4.6** | 4.4** | 4.4** | 3.6** | 3.2** | 3.2** | 2.8** | 2.6** | 2.4** | 1.8** | 1.8** |

[a] Positive number indicates increase in spring afternoon surface temperature mean for the urban/industrial cover/soil type compared to that of the left-column urban/industrial cover/soil type. The urban/industrial cover/soil types are denoted as follows: UCS =

Table 14--continued.

urban center on deep sand, UCR = urban center on sandy rockland, UCU = urban center on upland loamy sand, USS = suburb on deep sand, UCF = urban center on flatwoods sand, UMS = titanium mine on deep sand, USU = suburb on upland loamy sand, UGF = golf-course suburb on flatwoods sand, UMF = phosphate mine on flatwoods sand, USF = suburb on flatwoods sand, USC = suburb on coastal sand, UPF = platted suburb on flatwoods sand, and USR = suburb on sandy rockland. These cover/soil types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

mine on flatwoods sand was significant, but not substantial. The slightly lower AST for phosphate mine can be attributed to the presence of settling ponds. In zone N in spring, soil type appears to have a substantial effect on the AST for most suburbs, but not for urban centers (except on deep sand). This can be attributed to the larger fraction of paved surface area for urban centers, compared to suburbs.

Urban/industrial type impacts on soil type temperatures were compared. Among the deep sand combinations, urban center had higher AST than did suburb (by 1.0 C) or titanium mine (by 2.2 C). Suburb had higher AST (by 1.2 C) than did titanium mine. Among the rockland combinations, urban center had higher AST (by 4.6 C) than did suburb. Among the upland loamy sand combinations, urban center had higher AST (by 1.4 C) than did suburb. Among the flatwoods sand combinations, the highest difference in AST (2.0 C) was between urban center and platted suburb. Urban center had higher AST than did golf-course suburb (by 1.0 C), suburb (by 1.2 C), or phosphate mine (by 1.0 C). Golf-course suburb had higher AST (by 1.0 C) than did platted suburb. The differences in mean AST between golf-course suburb and suburb, suburb and phosphate mine, and between suburb and platted suburb, were significant, but not substantial. There was no significant difference between golf-course suburb and phosphate mine. There was only one cover type present on coastal sand (suburb). In zone N in spring, most urban/industrial cover types had a substantial effect on the AST for a given soil type. The overall trend

was an increase in AST for an increase in pavement fraction (from mine to suburb to urban center).

<u>Zone S.</u> Within zone S, there were five urban/industrial cover types present on up to five different soil types. Listed in order of decreasing AST (C) means, the combinations included golf-course suburb on flatwoods sand (35.0), urban center on sandy rockland (34.0), golf-course suburb on sandy rockland (31.6), urban center on muck (30.8), urban center on flatwoods sand (30.6), suburb on flatwoods sand (29.4), finger-canal suburb on flatwoods sand (28.4), suburb on marly rockland (27.6), Indian reservation on flatwoods sand (27.2), and finger-canal suburb on coastal sand (26.0). Differences in mean AST among zone S urban/industrial cover/soil type combinations are given in Table 15; most were significant, and many were substantial. Among these land cover types, the highest AST difference (9.0 C) was between golf-course suburb on flatwoods sand and finger-canal suburb on coastal sand.

Soil type impacts on urban/industrial type temperatures were compared. Among the suburb combinations, the highest difference in AST (9.0 C) was between golf-course suburb on flatwoods sand and finger-canal suburb on coastal sand. The differences between finger-canal suburb on flatwoods sand and suburb on marly rockland, and between suburb on marly rockland and Indian reservation on flatwoods sand were significant, but not substantial. Differences in AST among other suburb combinations were both significant and substantial. Among the urban center combinations, the highest difference in AST

Table 15. Spring afternoon surface temperature differences among urban/industrial land-cover types in south zone.

| Urban/ indus. cover/ soil type | Difference in AST (C) mean for urban/industrial cover/soil type[a] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | UGF | UCR | UGR | UCM | UCF | USF | UFF | USL | URF |
| UCR | 0.8** | | | | | | | | |
| UGR | 3.4** | 2.6** | | | | | | | |
| UCM | 4.2** | 3.4** | 0.8** | | | | | | |
| UCF | 4.4** | 3.4** | 0.8** | 0.2 | | | | | |
| USF | 5.4** | 4.6** | 2.0** | 1.4** | 1.2** | | | | |
| UFF | 6.6** | 5.8** | 3.2** | 2.4** | 2.2** | 1.2** | | | |
| USL | 7.4** | 6.6** | 4.0** | 3.2** | 3.0** | 1.8** | 0.8** | | |
| URF | 7.8** | 7.0** | 4.4** | 3.6** | 3.4** | 2.4** | 1.2** | 0.4** | |
| UFC | 9.0** | 8.2** | 5.6** | 4.8** | 4.6** | 3.4** | 2.4** | 1.6** | 1.2** |

[a] Positive number indicates increase in spring afternoon surface temperature mean for the urban/industrial cover/soil type compared to that of the left-column urban/industrial cover/soil type. The urban/industrial cover/soil types are denoted as follows: UGF = golf-course suburb on flatwoods sand, UCR = urban center on sandy rockland, UGR = golf-course suburb on sandy rockland, UCM = urban center on muck, UCF = urban center on flatwoods sand, USF = suburb on flatwoods sand, UFF = finger-canal suburb on flatwoods sand, USL = suburb on marly rockland, URF = Indian reservation on flatwoods sand, and UFC = finger-canal suburb on coastal sand. These cover/soil types are further described in the text.

Table 15--continued.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

(3.4 C) was between that on sandy rockland and that on flatwoods sand. Urban center on sandy rockland had higher AST (by 3.4 C) than did that on muck. There was no significant difference between urban center on muck and that on flatwoods sand. In zone S in spring, soil type appears to have a substantial effect on the AST for most suburb and urban center cover types.

Urban/industrial type impacts on soil type temperatures were compared. Among the flatwoods sand combinations, the highest difference in AST (7.8 C) was between golf-course suburb and Indian reservation. Differences in AST among all of the flatwoods sand combinations were both significant and substantial. In particular, golf-course suburb had higher AST (by 5.4 C) than did suburb, and suburb had higher AST (by 1.2 C) than did finger-canal suburb. This can be attributed to the effects of golf-course windbreak vegetation, and to the moderating effects of the fractional water surface in finger canals. Among the sandy rockland combinations, urban center had higher AST (by 2.6 C) than did golf-course suburb. In zone S in spring, urban/industrial cover type appears to have a substantial effect on the AST for a given soil type.

### Spring Afternoon Change Analyses--Natural to Agricultural Land-Cover

Zone P. Differences in mean AST between zone P agricultural/soil type combinations and their original cover types are given in Table 16. Mixed agriculture on deep sand

Table 16. Spring afternoon surface temperature change from natural to agricultural in panhandle zone.

| Soil type and natural cover | Difference in AST (C) mean for agricultural cover type[a] | |
|---|---|---|
| | Pasture/range | Mixed |
| Sand, deep (mixed scrub) | --- | 2.0** |
| Sand, loamy (upland mixed forest) | --- | 1.0** |
| Sand, flatwoods (flatwoods forest) | -1.0** | --- |

[a] Positive number indicates increase in spring afternoon surface temperature mean for agricultural cover type compared to that of the natural cover for the soil type.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

had a higher AST (by 2.0 C) than did the mixed scrub which was its original land cover. Mixed agriculture on upland loamy sand had a higher AST (by 1.0 C) than did the upland mixed forest which was its original land cover. Pasture/range on flatwoods sand had a lower AST (by 1.0 C) than did the flatwoods forest which was its original land cover. Within zone P in spring, conversion from natural to mixed agriculture use appears to increase AST on deep sand and upland loamy sand, while conversion from natural to pasture/range use appears to decrease AST on flatwoods sand.

Zone N. Differences in mean AST between zone N agricultural/soil type combinations and their original cover types are given in Table 17. Among the mixed agriculture combinations, that on upland loamy sand had higher mean AST (by 2.8 C) than did upland forest, that on sandy rockland had higher AST (by 2.4 C) than did calcareous hammock (represented by upland mixed forest), and that on deep sand had higher AST (by 1.0 C) than did mixed scrub. The difference between mixed agriculture on flatwoods sand and the flatwoods forest (its original cover) was significant, but not substantial. In zone N in spring, conversion from natural to mixed agriculture use appears to increase AST on upland loamy sand, deep sand, and sandy rockland, but appears to have no substantial effect on flatwoods sand. Row-crops on muck had higher AST (by 3.0 C) than did the marsh which was its original land cover. In zone N in spring, conversion from natural to row-crops use appears to increase AST on muck. Among the pasture combinations,

Table 17. Spring afternoon surface temperature change from natural to agricultural in north zone.

| Soil type and natural cover | Difference in AST (C) mean for agricultural cover type[a] | | | | |
|---|---|---|---|---|---|
| | Row-crops | Pasture/ range | Pasture/ sod | Citrus orchard | Mixed |
| Sand, deep (mixed scrub) | --- | --- | --- | --- | 1.0** |
| Sand, deep (evergreen scrub) | --- | --- | --- | 1.4** | --- |
| Sand, loamy (upland mixed forest) | --- | --- | --- | 3.0** | 2.8** |
| Sand, flatwoods (flatwoods forest) | --- | 0.6** | --- | 1.4** | 0.2** |
| Rockland, sandy (calcareous hammock[b]) | --- | --- | --- | --- | 2.4** |
| Organic, muck (marsh) | 3.0** | --- | 1.6** | --- | --- |

[a] Positive number indicates increase in spring afternoon surface temperature mean for agricultural cover type compared to that of the natural cover for the soil type.

[b] Represented by upland mixed forest.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

pasture/sod on muck had higher AST (by 1.6 C) than did marsh. The difference between pasture/ range on flatwoods sand and flatwoods forest was significant, but not substantial. In zone N in spring, conversion from natural to pasture use appears to increase AST on muck, but not on flatwoods sand. Among the citrus orchard combinations, that on upland loamy sand had higher AST (by 3.0 C) than did the upland forest, that on deep sand had higher AST (by 1.4 C) than did evergreen scrub, and that on flatwoods sand had higher AST (by 1.4 C) than did flatwoods forest. In zone N in spring, conversion from natural to citrus orchard use appears to increase AST on all soil types.

<u>Zone S.</u> Differences in mean AST between zone S agricultural/soil type combinations and their original cover types are given in Table 18. Among the mixed agriculture combinations, that on flatwoods sand had higher AST (by 1.4 C) than did flatwoods forest, that on sandy rockland had higher AST (by 2.6 C) than did rockland hammock, that on marly rockland had higher AST (by 1.0 C) than did rockland hammock, and that on muck had higher AST (by 5.8 C) than did marsh. Among the row-crops combinations, that on flatwoods sand had higher AST (by 3.4 C) than did flatwoods forest, and that on coastal sand had higher AST (by 1.4 C) than did coastal hammock. The difference between row-crops on marly rockland and rockland hammock was significant, but not substantial. Among the pasture combinations, pasture/range on sandy rockland had higher AST (by 1.0 C) than did rockland hammock,

Table 18. Spring afternoon surface temperature change from natural to agricultural in south zone.

| Soil type and natural cover | Difference in AST (C) mean for agricultural cover type[a] | | | | |
|---|---|---|---|---|---|
| | Row-crops | Pasture/range | Pasture/sod | Citrus orchard | Mixed |
| Sand, deep (evergreen scrub) | --- | --- | --- | 0.4** | --- |
| Sand, flatwoods (flatwoods forest) | 3.4** | 0.4** | --- | 0.8** | 1.4** |
| Sand, coastal (coastal hammock) | 1.4** | --- | --- | --- | --- |
| Rockland, sandy (rockland hammock) | --- | 1.0** | --- | --- | 2.6** |
| Rockland, marly (rockland hammock) | -0.6** | --- | --- | --- | 1.0** |
| Organic, muck (marsh) | --- | --- | 2.6** | --- | 5.8** |

[a] Positive number indicates increase in spring afternoon surface temperature mean for agricultural cover type compared to that of the natural cover for the soil type.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

and pasture/sod on muck had higher AST (by 2.6 C) than did marsh. The difference between pasture/range on flatwoods sand and flatwoods forest was significant, but not substantial. Among the citrus orchard combinations, the differences between citrus orchard on deep sand and evergreen scrub, and between citrus orchard on flatwoods sand and flatwoods forest, were significant, but not substantial. In zone S in spring, conversion from natural to mixed agriculture use appears to increase AST on all soil types. Conversion from natural to row-crops use appears to increase AST on flatwoods sand and coastal sand, but not (substantially) on marly rockland. Conversion from natural to pasture use appears to increase AST on sandy rockland and muck, but not (substantially) on flatwoods sand. Conversion from natural to citrus orchard use appears to have no substantial effect on AST.

### Spring Afternoon Change Analyses--Natural to Urban/Industrial Land-Cover

Zone P. Differences in mean AST between zone P urban/industrial cover/soil type combinations and their original cover types are given in Table 19. Urban center on deep sand had a higher AST (by 1.4 C) than did the mixed scrub which was its original land cover. Urban center on upland loamy sand had higher AST (by 2.4 C) than did the upland mixed forest which was its original land cover. Urban center on coastal sand had higher AST (by 2.2 C) than did the coastal hammock which was its original land cover. The difference between

Table 19. Spring afternoon surface temperature change from natural to urban/industrial in panhandle zone.

| Soil type and natural cover | Difference in AST (C) mean for urban/industrial cover type[a] | |
|---|---|---|
| | Suburb | Urban center |
| Sand, deep (mixed scrub) | --- | 1.4** |
| Sand, loamy (upland mixed forest) | --- | 2.4** |
| Sand, flatwoods (flatwoods forest) | --- | 0.8** |
| Sand, coastal (coastal hammock) | 1.4** | 2.2** |

[a] Positive number indicates increase in spring afternoon surface temperature mean for urban/industrial cover type compared to that of the natural cover for the soil type.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

urban center on flatwoods sand and flatwoods forest (its original land cover) was significant, but not substantial. Within zone P in spring, conversion from natural to urban center use on deep sand, upland loamy sand, and coastal sand appears to increase AST. Within zone P in spring, conversion from natural to urban center use on flatwoods sand appears to have no substantial effect on AST. Suburb on coastal sand had higher AST (by 1.4 C) than did the coastal hammock which was its original land cover. Within zone P in spring, conversion from natural to suburban use on coastal sand appears to increase AST.

Zone N. Differences in mean AST between zone N urban/ industrial cover/soil type combinations and their original cover types are given in Table 20. Among the suburb combinations, suburb on deep sand had higher AST (by 1.2 C) than did the evergreen scrub which was its original cover type. Suburb on upland loamy sand had higher AST (by 1.4 C) than did upland mixed forest. Suburb on coastal sand had higher AST (by 2.8 C) than did coastal hammock. Golf-course suburb on flatwoods sand had higher AST (by 1.0 C) than did flatwoods forest. The differences in AST between suburb on flatwoods sand and flatwoods forest, between suburb on sandy rockland and rockland hammock, and between platted suburb on flatwoods sand and flatwoods forest, were significant but not substantial. Among the urban center combinations, urban center on deep sand had higher AST than did evergreen scrub (by 2.2 C). Urban center on upland loamy sand had higher AST

Table 20. Spring afternoon surface temperature change from natural to urban/industrial in north zone.

| Soil type and natural cover | Difference in AST (C) mean for urban/industrial cover type[a] | | | | | |
|---|---|---|---|---|---|---|
| | Suburb | Platted suburb | Golf-course suburb | Urban center | Phos. mine | Titan. mine |
| Sand, deep (mixed scrub) | --- | --- | --- | --- | --- | $-0.6^{**}$ |
| Sand, deep (evergreen scrub) | $1.2^{**}$ | --- | --- | $2.2^{**}$ | --- | --- |
| Sand, loamy (upland mixed forest) | $1.4^{**}$ | --- | --- | $2.8^{**}$ | --- | --- |
| Sand, flatwoods (flatwoods forest) | $0.6^{**}$ | $0.2^{**}$ | $1.0^{**}$ | $2.0^{**}$ | $1.0^{**}$ | --- |
| Sand, coastal (coastal hammock) | $2.8^{**}$ | --- | --- | --- | --- | --- |
| Rockland, sandy (rockland hammock) | $0.8^{**}$ | --- | --- | --- | --- | --- |
| Rockland, sandy (calcareous hammock[b]) | --- | --- | --- | $2.8^{**}$ | --- | --- |

Table 20--continued.

[a] Positive number indicates increase in spring afternoon surface temperature mean for urban/industrial cover type compared to that of the natural cover for the soil type.

[b] Represented by upland mixed forest.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

(by 2.8 C) than did upland mixed forest. Urban center on flatwoods sand had higher AST (by 2.0 C) than did flatwoods forest. Urban center on sandy rockland had higher AST (by 2.8 C) than did the calcareous hammock (represented by upland mixed forest) which was its original cover. Among the mine combinations, phosphate mine on flatwoods sand had higher AST (by 1.0 C) than did flatwoods forest. The difference in AST between titanium mine on deep sand and mixed scrub was significant, but not substantial. In zone N in spring, conversion of natural cover to suburb, golf-course suburb, urban center, or phosphate mine use appears to increase AST for most soil types. In zone N in spring, conversion of natural cover to titanium mine use on deep sand, to suburb on sandy rockland, and to either suburb or platted suburb on flatwoods sand, appears to have no substantial effect on AST.

<u>Zone S.</u> Differences in mean AST between zone S urban/industrial soil type combinations and their original cover types are given in Table 21. Among the suburb combinations, suburb, finger-canal suburb, and golf-course suburb on flatwoods sand had higher AST than did flatwoods forest (by 2.2, 1.0, and 7.6 C, respectively). The difference between Indian reservation on flatwoods sand and flatwoods forest, was significant, but not substantial. Finger-canal suburb on coastal sand had higher AST (by 1.4 C) than did coastal hammock. Golf-course suburb on sandy rockland had higher AST (by 3.8 C) than did rockland hammock. There was no significant difference between suburb on marly rockland and

Table 21. Spring afternoon surface temperature change from natural to urban/industrial in south zone.

| Soil type and natural cover | Difference in AST (C) mean for urban/industrial cover type[a] | | | | |
|---|---|---|---|---|---|
| | Suburb | Finger-canal suburb | Golf-course suburb | Indian reserv. | Urban center |
| Sand, flatwoods (flatwoods forest) | 2.2** | 1.0** | 7.6** | -0.2** | 3.4** |
| Sand, coastal (coastal hammock) | --- | 1.4** | --- | --- | --- |
| Rockland, sandy (rockland hammock) | --- | --- | 3.8** | --- | 6.4** |
| Rockland, marly (rockland hammock) | 0.0 | --- | --- | --- | --- |
| Organic, muck (marsh) | --- | --- | --- | --- | 4.6** |

[a] Positive number indicates increase in spring afternoon surface temperature mean for urban/industrial cover type compared to that of the natural cover for the soil type.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

rockland hammock. Among the urban center combinations, that on flatwoods sand had higher AST (by 3.4 C) than did flatwoods forest. Urban center on sandy rockland had higher AST (by 6.4 C) than did rockland hammock. Urban center on muck had higher AST (by 4.6 C) than did marsh. In zone S in spring, conversion from natural to suburb, finger-canal suburb, golf-course suburb, or urban center use appeared to increase AST for all soil types (except marly rockland). Conversion from natural to Indian reservation cover appeared to have no substantial effect on AST.

### Spring Afternoon Change Analyses--Agricultural to Urban/ Industrial Land-Cover.

Zone P. Differences in mean AST between zone P urban/industrial cover/soil type combinations and their agricultural counterparts are given in Table 22. Urban center on upland loamy sand had higher AST (by 1.4 C) than did mixed agriculture on upland loamy sand. The difference in mean AST between urban center and mixed agriculture on deep sand was significant, but not substantial. Urban center on flatwoods sand had higher AST (by 1.8 C) than did pasture/range on flatwoods sand. Within zone P in spring, conversion from mixed agriculture to urban center use appears to increase AST on upland loamy sand, but has no substantial effect on deep sand. Within zone P in spring, conversion of pasture/range to urban center on flatwoods sand appears to increase AST.

Table 22. Spring afternoon surface temperature change from agricultural to urban/industrial in panhandle zone.

| Soil type and agric. cover | Difference in AST (C) mean for urban/industrial cover type[a] |
| --- | --- |
| | Urban center |
| Sand, deep (mixed agric.) | -0.6** |
| Sand, loamy (mixed agric.) | 1.4** |
| Sand, flatwoods (pasture/ range) | 1.8** |

[a] Positive number indicates increase in spring afternoon surface temperature mean for urban/industrial cover type compared to that of the agricultural cover for the soil type.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Zone N. Differences in mean AST between zone N urban/industrial cover/soil type combinations and their agricultural counterparts are given in Table 23. Among the deep sand combinations, titanium mine had lower AST than did citrus orchard (by 1.4 C) or mixed agriculture (by 1.6 C). The differences between either urban center or suburb and either citrus orchard or mixed agriculture were significant, but not substantial. In zone N in spring, conversion of citrus orchard or mixed agriculture to titanium mine on deep sand appears to decrease AST, while conversion from agricultural to urban center or suburb use appears to have no substantial effect. On upland loamy sand, the difference between urban center and citrus orchard was significant, but not substantial. There was no significant difference in AST between urban center and mixed agriculture. Suburb had lower AST (by 1.4 C) than did either citrus orchard or mixed agriculture. In zone N in spring, conversion from agricultural to suburb use on upland loamy sand appears to decrease AST, while conversion from agricultural to urban center use appears to have no substantial effect on AST. On flatwoods sand, urban center had higher AST than did pasture/range (by 1.4 C) or mixed agriculture (by 1.8 C). Platted suburb had a lower AST than did citrus orchard (by 1.2 C). There were no significant differences between suburb and pasture/range, or between platted suburb and mixed agriculture. The differences in AST between other combinations of urban/industrial cover and agricultural cover

Table 23. Spring afternoon surface temperature change from agricultural to urban/industrial in north zone.

| Soil type and agric. cover | Difference in AST (C) mean for urban/industrial cover type[a] | | | | | |
|---|---|---|---|---|---|---|
| | Suburb | Platted suburb | Golf-course suburb | Urban center | Phos. mine | Tita. mine |
| Sand, deep (citrus orchard) | $-0.2^{*}$ | --- | --- | $0.8^{**}$ | --- | $-1.4^{**}$ |
| Sand, deep (mixed agric.) | $-0.4^{**}$ | --- | --- | $0.6^{**}$ | --- | $-1.6^{**}$ |
| Sand, loamy (citrus orchard) | $-1.4^{**}$ | --- | --- | $-0.2^{*}$ | --- | --- |
| Sand, loamy (mixed agric.) | $-1.4^{**}$ | --- | --- | 0.0 | --- | --- |
| Sand, flatwoods (pasture/ range) | 0.0 | $-0.6^{**}$ | $0.4^{**}$ | $1.4^{**}$ | $0.4^{**}$ | --- |
| Sand, flatwoods (citrus orchard) | $-0.8^{**}$ | $-1.2^{**}$ | $-0.4^{**}$ | $0.6^{**}$ | $-0.4^{**}$ | --- |
| Sand, flatwoods (mixed agric.) | $0.4^{**}$ | 0.0 | $0.8^{**}$ | $1.8^{**}$ | $0.8^{**}$ | --- |
| Rockland, sandy (mixed agric.) | --- | --- | --- | $0.6^{**}$ | --- | --- |

Table 23--continued.

[a] Positive number indicates increase in spring afternoon surface temperature mean for urban/industrial cover type compared to that of the agricultural cover for the soil type.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

were significant, but not substantial. In zone N in spring, conversion of pasture/range or mixed agriculture to urban center on flatwoods sand appears to increase AST. In zone N in spring, conversion of citrus orchard to platted suburb on flatwoods sand appears to decrease AST. Conversion of pasture/range to suburb, platted suburb, or golf-course suburb; citrus orchard to suburb, golf-course suburb, or urban center; mixed agriculture to suburb, platted suburb, or golf-course suburb; and any agriculture to phosphate mine on flatwoods sand appear to have no substantial effect on AST. On sandy rockland, the difference between urban center and mixed agriculture was significant, but not substantial. In zone N in spring, conversion of mixed agriculture to urban center appears to have no substantial effect on AST.

Zone S. Differences in mean AST between zone S urban/industrial cover/soil type combinations and their agricultural counterparts are given in Table 24. Among the flatwoods sand combinations, golf-course suburb had higher AST than did all agriculture types, while Indian reservation had lower AST (or no substantial difference) than did all agriculture types. Suburb had higher AST than did pasture/range or citrus orchard, but lower AST than did row-crops. The difference between suburb and mixed agriculture was significant, but not substantial. The difference between finger-canal suburb and pasture/range, citrus orchard, and mixed agriculture was significant, but not substantial. All urban types (except golf-course suburb) had lower AST than did

Table 24. Spring afternoon surface temperature change from agricultural to urban/industrial in south zone.

| Soil type | Difference in AST (C) mean for urban/industrial cover type[a] | | | | |
|---|---|---|---|---|---|
| | Suburb | Finger-canal suburb | Golf-course suburb | Indian reserv. | Urban center |
| Sand, flatwoods (row-crops) | -1.4** | -2.4** | 4.2** | -3.6** | -0.2** |
| Sand, flatwoods (pasture/range) | 1.6** | 0.6** | 7.2** | -0.6** | 2.8** |
| Sand, flatwoods (citrus orchard) | 1.4** | 0.2 | 7.2** | -0.6** | 3.0** |
| Sand, flatwoods (mixed agric.) | 0.6** | -0.4** | 6.2** | -1.6** | 1.8** |
| Sand, coastal (row-crops) | --- | 0.0 | --- | --- | --- |
| Rockland, sandy (pasture/range) | --- | --- | 3.0** | --- | 5.4** |
| Rockland, sandy (mixed agric.) | --- | --- | 1.2** | --- | 3.8** |
| Rockland, marly (row-crops) | 0.6** | --- | --- | --- | --- |
| Rockland, marly (mixed agric.) | -1.2** | --- | --- | --- | --- |
| Organic, muck (pasture/sod) | --- | --- | --- | --- | 1.8** |
| Organic, muck (mixed agric.) | --- | --- | --- | --- | -1.2** |

[a] Positive number indicates increase in spring afternoon surface temperature mean for urban/industrial cover type compared to that of the agricultural cover for the soil type.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

row-crops. In zone S in spring, conversion from pasture/range or citrus orchard to urban/industrial use (other than Indian reservation) on flatwoods sand appears to increase AST. For row-crops, the effect of conversion to urban/industrial use (other than golf-course suburb) on flatwoods sand appears to decrease AST. Among the coastal sand combinations, there was no significant difference between finger-canal suburb and row-crops. Among the sandy rockland combinations, all urban/industrial types had higher AST than did their agricultural counterparts. In zone S in spring, conversion from agricultural to urban/industrial use appears to increase AST on sandy rockland. Among the marly rockland combinations, suburb had lower AST than did mixed agriculture. The difference between suburb and row-crops was significant, but not substantial. In zone S in spring, conversion from mixed agriculture to suburb use on marly rockland appears to decrease AST, while conversion from row-crops to suburb use appears to have no substantial effect. Among the muck combinations, urban center had higher AST than did pasture/sod, but had lower AST than did mixed agriculture. In zone S in spring, conversion from pasture/sod to urban center on muck appears to increase AST, while conversion from mixed agriculture to urban center on muck appears to decrease AST.

## Spring Afternoon Comparison of Agricultural to Natural Heat Islands

Zone P. Differences in mean AST between agricultural cover types and the hottest natural feature of zone P (mixed scrub) are given in Table 25. Mixed agriculture on deep sand had higher AST (by 2.0 C) than did the mixed scrub. The difference between mixed agriculture on upland loamy sand and mixed scrub was significant, but not substantial. Pasture/ range on flatwoods sand had lower AST than did the mixed scrub. Within zone P in spring, mixed agriculture on upland loamy sand had AST matching that of the hottest natural feature, but mixed agriculture on deep sand had AST exceeding it.

Zone N. Differences in mean AST between agricultural cover types and the hottest natural feature of zone N (mixed scrub) are given in Table 25. Mixed agriculture on deep sand had higher AST (by 1.0 C) than did mixed scrub. Pasture/range on flatwoods sand, pasture/sod on muck, and mixed agriculture on flatwoods sand had lower AST than did mixed scrub. The differences between either citrus orchard (on all soil types), row-crops (on muck), or mixed agriculture (on upland loamy sand and sandy rockland) and mixed scrub were significant, but not substantial. In zone N in spring, several agricultural combinations matched the AST of the hottest natural feature, but mixed agriculture on deep sand was the only agricultural type with AST that substantially exceeded it.

Table 25. Spring afternoon surface temperature of agricultural land-cover types vs hottest natural land-cover.

| Soil type | Difference in AST (C) mean for agricultural cover type[a] | | | | |
|---|---|---|---|---|---|
| | Row-crops | Pasture/ range | Pasture/ sod | Citrus orchard | Mixed |
| Zone P | | | | | |
| Sand, deep | --- | --- | --- | --- | 2.0** |
| Sand, loamy | --- | --- | --- | --- | 0.4** |
| Sand, flatwoods | --- | -2.4** | --- | --- | --- |
| Zone N | | | | | |
| Sand, deep | --- | --- | --- | 0.8** | 1.0** |
| Sand, loamy | --- | --- | --- | 0.8** | 0.8** |
| Sand, flatwoods | --- | -1.4** | --- | -0.8** | -2.0** |
| Rockland, sandy | --- | --- | --- | --- | 0.2** |
| Organic, muck | 0.4* | --- | -1.0** | --- | --- |
| Zone S | | | | | |
| Sand, deep | --- | --- | --- | 0.4** | --- |
| Sand, flatwoods | 1.2** | -1.8** | --- | -1.4** | -0.8** |
| Sand, coastal | -3.6** | --- | --- | --- | --- |
| Rockland, sandy | --- | -1.0** | --- | --- | 0.8** |
| Rockland, marly | -2.6** | --- | --- | --- | -0.8** |
| Organic, muck | --- | --- | -0.4** | --- | 2.4** |

[a] Positive number indicates increase in spring afternoon surface temperature mean for agricultural cover type compared to that of hottest natural cover type (mixed scrub in zones P and N, evergreen scrub in zone S).

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

<u>Zone S.</u> Differences in mean AST between agricultural cover types and the hottest natural feature of zone S (evergreen scrub) are given in Table 25. Among the row-crops combinations, row-crops on flatwoods sand had higher AST (by 1.2 C) than did evergreen scrub. Row-crops on coastal sand and on marly rockland had lower AST than did evergreen scrub. Among the pasture combinations, the difference between pasture/sod on muck and evergreen scrub was significant, but not substantial. Pasture/range on flatwoods sand and on sandy rockland had lower AST than did evergreen scrub. Among the citrus orchard combinations, the difference between citrus orchard on deep sand and evergreen scrub was significant, but not substantial. Citrus orchard on flatwoods sand had lower AST than did evergreen scrub. Among the mixed agriculture combinations, that on muck had higher AST than did evergreen scrub. The difference between evergreen scrub and mixed agriculture on either flatwoods sand, sandy rockland, or marly rockland was significant, but not substantial. In zone S in spring, mixed agriculture (on flatwoods sand, sandy rockland, and marly rockland), pasture/sod on muck, and citrus orchard on deep sand had AST matching that of the hottest natural feature. Row-crops on flatwoods sand and mixed agriculture on muck exceeded the AST of the hottest natural feature.

## Spring Afternoon Comparison of Urban/Industrial to Natural Heat Islands

Zone P. Differences in mean AST between urban/industrial cover types and the hottest natural feature of zone P (mixed scrub) are given in Table 26. Urban center on deep sand and on upland loamy sand had higher AST (by 1.4 and 1.8 C, respectively) than did the mixed scrub. Urban center and suburb on coastal sand had lower AST (by 2.2 and 3.0 C, respectively) than did the mixed scrub. The difference between urban center on flatwoods sand and mixed scrub was significant, but not substantial. Within zone P in spring, urban center on flatwoods sand had AST matching that of the hottest natural feature, but urban center on deep sand and on upland loamy sand had AST exceeding it.

Zone N. Differences in mean AST between urban/industrial cover types and the hottest natural feature of zone N (mixed scrub) are given in Table 26. Urban center on deep sand had higher AST than did mixed scrub. Suburb on flatwoods sand, platted suburb on flatwoods sand, golf-course suburb on flatwoods sand, phosphate mine on flatwoods sand, suburb on coastal sand, and suburb on sandy rockland all had lower AST than did mixed scrub. The differences between mixed scrub and suburb on deep sand, suburb on upland loamy sand, titanium mine on deep sand, urban center on upland loamy sand, and urban center on sandy rockland were significant, but not substantial. There was no significant difference in AST between urban center on flatwoods sand and mixed scrub. In

Table 26. Spring afternoon surface temperature of urban/industrial land-cover types vs hottest natural land-cover.

| Soil type | Difference in AST (C) mean for urban/industrial cover type[a] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Suburb | Platted suburb | Finger-canal suburb | Golf-course suburb | Indian reserv. | Urban center | Phos. mine | Tita. mine |
| Zone P | | | | | | | | |
| Sand, deep | --- | --- | --- | --- | --- | 1.4** | --- | --- |
| Sand, loamy | --- | --- | --- | --- | --- | 1.8** | --- | --- |
| Sand, flatwoods | --- | --- | --- | --- | --- | -0.6** | --- | --- |
| Sand, coastal | -3.0** | --- | --- | --- | --- | -2.2** | --- | --- |
| Zone N | | | | | | | | |
| Sand, deep | 0.6** | --- | --- | --- | --- | 1.6** | --- | -0.6** |
| Sand, loamy | -0.6** | --- | --- | --- | --- | 0.6** | --- | --- |
| Sand, flatwoods | -1.4** | -2.0** | --- | -1.0** | --- | 0.0 | -1.0** | --- |
| Sand, coastal | -2.0** | --- | --- | --- | --- | --- | --- | --- |
| Rockland, sandy | -3.8** | --- | --- | --- | --- | 0.8** | --- | --- |

Table 26--continued.

| Soil type | Difference in AST (C) mean for urban/industrial cover type[a] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Suburb | Platted suburb | Finger-canal suburb | Golf-course suburb | Indian reserv. | Urban center | Phos. mine | Tita. mine |
| Zone S | | | | | | | | |
| Sand, flatwoods | 0.0 | --- | $-1.2^{**}$ | $5.4^{**}$ | $-2.4^{**}$ | $1.2^{**}$ | --- | --- |
| Sand, coastal | --- | --- | $-3.6^{**}$ | --- | --- | --- | --- | --- |
| Rockland, sandy | --- | --- | --- | $2.0^{**}$ | --- | $4.6^{**}$ | --- | --- |
| Rockland, marly | $-2.0^{**}$ | --- | --- | --- | --- | --- | --- | --- |
| Organic, muck | --- | --- | --- | --- | --- | $1.2^{**}$ | --- | --- |

[a] Positive number indicates increase in spring afternoon surface temperature mean for urban/industrial cover type compared to that of hottest natural cover type (mixed scrub in zones P and N, evergreen scrub in zone S).

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

zone N in spring, several urban/industrial cover types had AST matching that of the hottest natural feature, but only urban center on deep sand exceeded it.

Zone S. Differences in mean AST between urban/industrial cover types and the hottest natural feature of zone S (evergreen scrub on deep sand) are given in Table 26. There was no significant difference between suburb on flatwoods sand and evergreen scrub. Suburb on marly rockland, finger-canal suburb on flatwoods sand and coastal sand, and Indian reservation on flatwoods sand all had lower AST than did evergreen scrub. Golf-course suburb on flatwoods sand and on sandy rockland, and urban center on flatwoods sand, sandy rockland, and muck all had AST higher than did evergreen scrub. In zone S in spring, suburb on flatwoods sand had AST matching that of the hottest natural feature, while golf-course suburb (on flatwoods sand and sandy rockland) and urban center (on flatwoods sand, sandy rockland, and muck) all had AST that exceeded that of the hottest natural feature.

## Spring Afternoon Change Analyses--Special Factors

Natural factors. Normal and droughty natural land-cover types were compared. As shown in Table 27, droughty bay swamp (mean 26.6 C) had higher AST (by 2.8 C) than did normal bay swamp. Droughty mixed swamp (mean 26.8 C) had higher AST (by 1.0 C) than did normal mixed swamp. The greater drought-related increase in AST for bay swamp than for mixed swamp can be attributed to the organic soil of bay swamp.

Table 27. Spring afternoon surface temperature change for special conditions.

| Zone | Difference in AST (C) mean for cover type under special condition[a] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Bay swamp[b] | Mixed swamp[c] | Citrus orchard[d] | Urban center[e] | Cypress swamp[f] | Marsh[g] | Marsh[h] | Flatwoods forest[i] |
| N | 2.8** | 1.0** | 0.6** | --- | --- | --- | --- | --- |
| S | --- | --- | --- | -3.6** | 0.2** | 0.6** | 3.0** | 2.6** |

[a] Positive number indicates increase in spring afternoon surface temperature mean for cover type under special condition compared to that of the cover type under normal condition.

[b] Bay swamps under drought condition in north-central Florida (Sandlin Bay and Little Santa Fe Lake area) compared to those under normal condition in central Florida (Chassahowitzka Swamp). See also Mixed Swamp note below.

[c] Mixed swamps under drought condition in north-central Florida and south Georgia (Okeefenokee N.W.R. south of Suwannee R., Pinhook Swamp) compared to those under normal condition in other areas (Okeefenokee N.W.R. north of Suwannee R., Withlacoochee State Forest southeast, Devils Hammock, Hull Cypress Swamp/Bennett Swamp, Spruce Creek Swamp, and Wekiva Swamp). The Okeefenokee N.W.R. hydrology is controlled by a system of dikes and canals along the Suwannee R. Wildfire broke out in the drought-stricken mixed swamp area two months (June 1993) after this image (April 1993).

[d] Citrus orchard (on deep sand) in area heavily damaged by freezes of mid 1980s (Okahumpka/Clermont area) compared to citrus orchard (on deep sand) in areas which had quickly recovered (Ft. Meade, east area and Lake Wales area).

[e] Urban center (Homestead/Leisure City area) on sandy rockland under heavily damaged condition--eight months (April 1993) after Hurricane Andrew (August 1992), compared to nearby urban center on sandy rockland under normal condition (Ft. Lauderdale/Miami).

Table 27--Continued.

[f] Disturbed dwarf-cypress swamp in abandoned platted subdivision (Golden Gate Estates, east area) compared to normal dwarf-cypress swamps nearby (Big Cypress National Preserve--central, southeast, and southwest).

[g] Marsh within the EAA canal system (Holey Land/Rotenberger Wildlife Management Areas) compared to marsh in less-impacted areas (Moonshine Bay area of Lake Okeechobee, Water Conservation Area 2, and Little Doctor Village/Custard Apple Hammock area of the deep Everglades).

[h] Marsh within an area heavily impacted by EAA drainage system (Water Conservation Area 1) compared to marsh in less-impacted areas (Moonshine Bay area of Lake Okeechobee, Water Conservation Area 2, and Little Doctor Village/Custard Apple Hammock area of the deep Everglades).

[i] Flatwoods forest (on flatwoods sand) in West Green Acres area invaded by exotic forest, compared to normal flatwoods forest in other areas (Gator Slough, C. M. Webb WMA, J. W. Corbett WMA, Keri area, and Rainey Slough).

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Freeze-damaged and normal citrus orchard land-cover were compared. As shown on Table 27, the difference in AST between freeze-damaged citrus orchard on deep sand and normal citrus orchard on deep sand was significant, but not substantial. The slight increase in AST for the damaged area may be attributed to the loss of tree canopy on abandoned groves, and to decreased canopy on groves converted to pine plantations (very young at image date) and vineyards.

Hurricane-damaged and normal urban/industrial land-cover types were compared. As shown in Table 27, hurricane-damaged urban center on sandy rockland (mean 30.4 C) had lower AST (by 3.6 C) than did normal urban center on sandy rockland. This can be attributed to the decrease in the fractional areal occupied by roof-tops after the hurricane (vegetation cover had already returned to the area).

Artificial factors. Disturbed and normal dwarf-cypress land-cover types were compared. As shown in Table 27, the difference in AST between disturbed dwarf cypress swamp (mean 26.8 C) and normal dwarf cypress swamp was significant, but not substantial.

Disturbed and normal marsh land-cover types were compared. As shown in Table 27, the difference in AST between marsh within the Holey Land/Rotenburger Wildlife Management Area of the EAA (mean 26.8 C) and normal marsh was significant, but not substantial. As shown in Table 27, marsh within the Water Conservation Area 1 (mean 29.2 C) had higher AST (by 3.0 C) than did normal marsh.

Exotic forest and normal flatwoods forest land-cover types were compared. As shown in Table 27, exotic forest (mean 29.8 C) had higher AST (by 2.6 C) than did normal flatwoods forest. These findings for disturbed wetlands and exotic-invaded flatwoods forest indicate that major disturbances (widespread change in vegetation species composition accompanied by/related to major hydrologic alteration) of natural communities can lead to increased AST.

Spring Nighttime Natural Land-Cover Thermal Patterns

Zone P. Within zone P in spring, eight natural land cover types were present. Listed in order of decreasing mean NST (C), these included coastal hammock (15.8), saltmarsh (14.8), deciduous hardwood swamp (14.8), marsh (14.4), bay swamp (12.6), flatwoods forest (11.2), mixed scrub (11.2), and upland mixed forest (11.0). Differences in mean NST among zone P natural land cover types are given in Table 28; most were significant, and many were substantial. The highest difference (4.8 C) was between mixed coastal hammock and upland mixed forest. The overall trend was a higher NST for the wetter natural land-cover types (marshes and swamps), and lower NST for the drier types (mixed scrub and upland mixed forest).

Zone N. Within zone N in spring, thirteen natural land cover types were present. Listed in order of decreasing mean NST (C), these included bay swamp (15.2), saltmarsh (15.0), coastal hammock (14.2), marsh (13.8), rockland hammock (13.4),

Table 28. Spring nighttime surface temperature differences among natural land-cover types in panhandle zone.

| Natural cover type | Difference in NST (C) mean for natural cover type[a] | | | | | | |
|---|---|---|---|---|---|---|---|
| | HCO | MRS | SHD | MRF | SBY | FLW | SCM |
| MRS | 1.0** | | | | | | |
| SHD | 1.0** | 0.0 | | | | | |
| MRF | 1.4** | 0.4 | 0.4 | | | | |
| SBY | 3.2** | 2.2** | 2.2** | 1.8** | | | |
| FLW | 4.6** | 3.6** | 3.6** | 3.2** | 1.4** | | |
| SCM | 4.6** | 3.6** | 3.6** | 3.2** | 1.4** | 0.0 | |
| FMX | 4.8** | 4.0** | 4.0** | 3.4** | 1.6** | 0.2** | 0.2** |

[a] Positive number indicates increase in spring nighttime surface temperature mean for the natural cover type compared to that of the left-column natural cover type. The natural cover types are denoted as follows: HCO = coastal hammock, MRS = saltmarsh, SHD = deciduous hardwood swamp, MRF = marsh, SBY = bay swamp, FLW = flatwoods forest, SCM = mixed scrub, and FMX = upland mixed forest. These natural cover types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

deciduous hardwood swamp (13.2), cypress swamp (13.2), mixed swamp (12.6), evergreen hardwood swamp (11.6), mixed scrub (11.6), upland mixed forest (11.4), evergreen scrub (11.4), and flatwoods forest (10.8). Differences in mean NST among zone N natural land cover types are given in Table 29; most were significant, and many were substantial. Among these natural land cover types, the highest difference (4.4 C) in NST was between bay swamp and flatwoods forest. The overall trend was a higher NST for the wetter natural land-cover types (swamps and marshes), and lower NST for the drier types (scrub, upland mixed forest). The low NST for flatwoods forest can be attributed to the spring dry season. Differences between evergreen and deciduous subtypes of scrub were significant, but not substantial--as expected from a spring date (deciduous subtypes in full foliage). Deciduous hardwood swamp had higher NST (by 1.6 C) than did evergreen hardwood swamp, which was expected, since it is a wetter type of swamp.

Zone S. Within zone S in spring, fourteen natural land cover types were present. Listed in order of decreasing mean NST (C), these included marsh (17.8), coastal hammock (16.2), mangrove swamp (16.2), brackish marsh (16.0), wet-prairie (15.2), dwarf cypress swamp (15.0), cypress swamp (14.8), flatwoods forest (14.8), deciduous shrubby marsh (14.8), evergreen hardwood swamp (13.8), mixed swamp (13.6), evergreen shrubby marsh (13.4), rockland hammock (13.2), and evergreen scrub (11.4). Differences in mean NST among zone S natural

Table 29. Spring nighttime surface temperature differences among natural land-cover types in north zone.

| Natural cover type | Difference in NST (C) mean for natural cover type[a] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SBY | MRS | HCO | MRF | HRO | SHD | SCY | SMX | SHE | SCM | FMX | SCE |
| MRS | 0.2 | | | | | | | | | | | |
| HCO | 1.0** | 0.8** | | | | | | | | | | |
| MRF | 1.4** | 1.2** | 0.4** | | | | | | | | | |
| HRO | 1.8** | 1.6** | 0.8** | 0.4** | | | | | | | | |
| SHD | 2.0** | 2.0** | 1.0** | 0.8** | 0.2** | | | | | | | |
| SCY | 2.0** | 2.0** | 1.0** | 0.8** | 0.2** | 0.0 | | | | | | |
| SMX | 2.6** | 2.6** | 1.8** | 1.4** | 0.8** | 0.6** | 0.6** | | | | | |
| SHE | 3.6** | 3.6** | 2.6** | 2.2** | 1.8** | 1.6** | 1.6** | 1.0** | | | | |
| SCM | 3.6** | 3.6** | 2.8** | 2.4** | 1.8** | 1.6** | 1.6** | 1.0** | 0.0 | | | |
| FMX | 3.8** | 3.8** | 2.8** | 2.4** | 2.0** | 1.8** | 1.8** | 1.2** | 0.2* | 0.2 | | |
| SCE | 3.8** | 3.8** | 2.8** | 2.6** | 2.0** | 1.8** | 1.8** | 1.2** | 0.2** | 0.2* | 0.0 | |
| FLW | 4.4** | 4.4** | 3.4** | 3.2** | 2.6** | 2.4** | 2.4** | 1.8** | 0.8** | 0.8** | 0.6** | 0.6** |

[a] Positive number indicates increase in spring nighttime surface temperature mean for the natural cover type compared to that of the left-column natural cover type. The natural cover types are denoted as follows: SBY = bay swamp, MRS = saltmarsh, HCO = coastal hammock, MRF = marsh, HRO = rockland hammock, SHD = deciduous hardwood swamp, SCY =

Table 29--Continued.

cypress swamp, SMX = mixed swamp, SHE = evergreen hardwood swamp, SCM = mixed scrub, FMX = upland mixed forest, SCE = evergreen scrub, and FLW = flatwoods forest. These natural cover types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

land cover types are given in Table 30; most were significant, and many were substantial. Among these natural land cover types, the highest difference (6.6 C) in NST was between marsh and evergreen scrub. The overall trend was a higher NST for the wetter natural land-cover types (marshes and swamps), and lower NST for the drier types (evergreen scrub). Deciduous shrubby marsh had higher NST (by 1.4 C) than did evergreen shrubby marsh, which can be attributed to the combination of the more open canopy of deciduous shrubby marsh; as will be discussed later, there was no substantial difference in DSTV (relative soil moisture) for these shrubby marsh subtypes. There was no significant difference in NST between dwarf-cypress swamp and cypress swamp.

Spring Nighttime Agricultural Land-Cover Thermal Patterns

Zone P. Within zone P, there were two types of agriculture distributed on three soil types. Listed in order of decreasing mean NST (C), these agricultural/soil type combinations included mixed agriculture on upland loamy sand (11.6), mixed agriculture on deep sand (11.2), and pasture/range on flatwoods sand (10.8). Differences in mean NST among zone P agricultural/soil type combinations are given in Table 31; all were significant, but none were substantial. The highest difference in NST (0.8 C) was between mixed agriculture on upland loamy sand and pasture/range on flatwoods sand.

Table 30. Spring nighttime surface temperature differences among natural land-cover types in south zone.

| Nat. cov. type | Difference in NST (C) mean for natural cover type[a] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | MRF | HCO | SMG | MRS | MRP | SCD | SCY | FLW | MSD | SHE | SMX | MSE | HRO |
| HCO | 1.6** | | | | | | | | | | | | |
| SMG | 1.6** | 0.0 | | | | | | | | | | | |
| MRS | 1.8** | 0.2* | 0.2* | | | | | | | | | | |
| MRP | 2.6** | 1.0** | 0.8** | 0.6** | | | | | | | | | |
| SCD | 2.8** | 1.2** | 1.2** | 1.0** | 0.4** | | | | | | | | |
| SCY | 3.0** | 1.4** | 1.4** | 1.0** | 0.4** | 0.2 | | | | | | | |
| FLW | 3.0** | 1.4** | 1.4** | 1.0** | 0.4** | 0.2 | 0.0 | | | | | | |
| MSD | 3.0** | 1.4** | 1.4** | 1.2** | 0.6* | 0.2 | 0.0 | 0.0 | | | | | |
| SHE | 4.0** | 2.4** | 2.4** | 2.2** | 1.4** | 1.2** | 1.0** | 1.0** | 1.0** | | | | |
| SMX | 4.2** | 2.6** | 2.6** | 2.4** | 1.8** | 1.4** | 1.4** | 1.4** | 1.2** | 0.2** | | | |
| MSE | 4.4** | 2.8** | 2.8** | 2.6** | 2.0** | 1.6** | 1.6** | 1.6** | 1.4** | 0.4* | 0.2 | | |
| HRO | 4.6** | 3.0** | 3.0** | 2.6** | 2.0** | 1.8** | 1.6** | 1.6** | 1.6** | 0.6** | 0.2** | 0.0 | |
| SCE | 6.6** | 5.0** | 4.8** | 4.6** | 4.0** | 3.6** | 3.6** | 3.6** | 3.4** | 2.6** | 2.2** | 2.0** | 2.0** |

[a] Positive number indicates increase in spring nighttime surface temperature mean for the natural cover type compared to that of the left-column natural cover type. The natural

Table 30--Continued.

cover types are denoted as follows: MRF = marsh, HCO = coastal hammock, SMG = mangrove swamp, MRS = saltmarsh, MRP = wet-prairie, SCD = dwarf-cypress swamp, SCY = cypress swamp, FLW = flatwoods forest, MSD = deciduous shrubby marsh, SHE = evergreen hardwood swamp, SMX = mixed swamp, MSE = evergreen shrubby marsh, HRO = rockland hammock, and SCE = evergreen scrub. These natural cover types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Table 31. Spring nighttime surface temperature differences among agricultural land-cover types in panhandle zone.

| Agricultural cover/soil type | Difference in NST (C) mean for agricultural cover/soil type[a] | |
|---|---|---|
| | AXU | AXS |
| AXS | 0.4** | |
| APF | 0.8** | 0.4** |

[a] Positive number indicates increase in spring nighttime surface temperature mean for the agricultural cover/soil type compared to that of the left-column agricultural cover/soil type. The agricultural cover/soil types are denoted as follows: AXU = mixed agriculture on upland loamy sand, AXS = mixed agriculture on deep sand, and APF = pasture/range on flatwoods sand. These cover/soil types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Zone N. Within zone N in spring, there were five agriculture types on up to five different soil types. Listed in order of decreasing mean NST (C), these combinations included row-crops on muck (13.4), mixed agriculture on flatwoods sand (13.4), citrus orchard on deep sand (13.2), pasture/range on flatwoods sand (12.4), citrus orchard on upland loamy sand (12.2), pasture/sod on muck (12.2), citrus orchard on flatwoods sand (11.8), mixed agriculture on deep sand (10.8), mixed agriculture on sandy rockland (10.4), and mixed agriculture on upland loamy sand (9.8). Differences in mean NST among zone N agricultural/soil type combinations are given in Table 32; most were significant, and many were substantial. Among these agricultural land cover types, the highest difference in NST (3.6 C) was between row-crops on muck and mixed agriculture on upland loamy sand.

Soil type impacts on agricultural type temperatures were compared. Among the mixed agriculture combinations, that on flatwoods sand had higher NST (by 2.6 C or more) than that on other soil types. The differences between mixed agriculture on deep sand, upland loamy sand, and sandy rockland were smaller. Among the pasture combinations, the difference in NST between pasture/sod on muck and pasture/range on flatwoods sand was significant, but not substantial. Among the citrus orchard combinations, that on deep sand had somewhat higher NST (by about 1.0 C) than did that on either upland loamy sand or flatwoods sand. There was no substantial difference in NST between citrus orchard on upland loamy sand and that on

Table 32. Spring nighttime surface temperature differences among agricultural land-cover types in north zone.

| Agric. cover/ soil type | Difference in NST (C) mean for agricultural cover/soil type[a] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | ARM | AXF | ACS | APF | ACU | ASM | ACF | AXS | AXR |
| AXF | 0.0 | | | | | | | | |
| ACS | 0.2 | 0.2 | | | | | | | |
| APF | 1.0** | 0.8** | 0.8** | | | | | | |
| ACU | 1.2** | 1.2* | 1.0** | 0.4** | | | | | |
| ASM | 1.2** | 1.2** | 1.2** | 0.4** | 0.0 | | | | |
| ACF | 1.6** | 1.6** | 1.4** | 0.6** | 0.4** | 0.4* | | | |
| AXS | 2.6** | 2.6** | 2.4** | 1.6** | 1.4** | 1.4** | 1.0** | | |
| AXR | 3.0** | 3.0** | 2.8** | 2.2** | 1.8** | 1.8** | 1.4** | 0.4** | |
| AXU | 3.6** | 3.4** | 3.4** | 2.6** | 2.2** | 2.2** | 2.0** | 1.0** | 0.4** |

[a] Positive number indicates increase in spring afternoon surface temperature mean for the agricultural cover/soil type compared to that of the left-column agricultural cover/soil type. The agricultural cover/soil types are denoted as follows: ARM = row-crops on muck, AXF = mixed agriculture on flatwoods sand, ACS = citrus orchard on deep sand, APF = pasture/range on flatwoods sand, ACU = citrus orchard on upland loamy sand, ASM = pasture/sod on muck, ACF = citrus orchard on flatwoods sand, AXS = mixed agriculture on deep sand, AXR = mixed agriculture on sandy rockland, and AXU = mixed agriculture on upland loamy sand. These cover/soil types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

flatwoods sand. In zone N in spring, flatwoods sand appears to raise the NST of mixed agriculture.

Agriculture type impacts on soil type temperatures were compared. Among the deep sand combinations, citrus orchard had higher NST (by 2.4 C) than did mixed agriculture. Among the upland loamy sand combinations, citrus orchard had higher NST (by 2.2 C) than did mixed agriculture. Among the flatwoods sand combinations, mixed agriculture had higher NST (by 1.6 C) than did citrus orchard, while other agricultural differences were significant, but not substantial. Among the muck combinations, row-crops had higher NST (by 1.2 C) than did pasture/sod. In zone N in spring, differences in AST among certain agricultural types were substantial on all soil types.

Zone S. Within zone S, there were five agriculture types on up to six different soil types. Listed in order of decreasing mean NST (C), these combinations included row-crops on coastal sand (16.2), row-crops on flatwoods sand (15.0), pasture/sod on muck (14.2), mixed agriculture on sandy rockland (13.2), pasture/range on sandy rockland (13.2), citrus orchard on flatwoods sand (13.0), citrus orchard on deep sand (12.8), mixed agriculture on marly rockland (12.6), pasture/range on flatwoods sand (12.6), row-crops on marly rockland (12.4), mixed agriculture on flatwoods sand (12.0), and mixed agriculture on muck (11.8). Differences in mean NST among zone S agricultural/soil type combinations are given in Table 33. Among these agricultural land cover types, the

Table 33. Spring nighttime surface temperature differences among agricultural land-cover types in south zone.

| Agric. cover/ soil type | Difference in NST (C) mean for agricultural cover/soil type[a] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | ARC | ARF | ASM | AXR | APR | ACF | ACS | AXL | APF | ARL | AXF |
| ARF | 1.2** | | | | | | | | | | |
| ASM | 2.2** | 0.8** | | | | | | | | | |
| AXR | 3.0** | 1.6** | 0.8** | | | | | | | | |
| APR | 3.0** | 1.8** | 1.0** | 0.0 | | | | | | | |
| ACF | 3.2** | 2.0** | 1.0** | 0.2* | 0.2 | | | | | | |
| ACS | 3.4** | 2.0** | 1.2** | 0.4** | 0.4** | 0.2 | | | | | |
| AXL | 3.6** | 2.2** | 1.4** | 0.6** | 0.6** | 0.4** | 0.2 | | | | |
| APF | 3.6** | 2.4** | 1.4** | 0.6** | 0.6** | 0.4** | 0.2** | 0.0 | | | |
| ARL | 3.8** | 2.6** | 1.8** | 1.0** | 0.8** | 0.6** | 0.4** | 0.4* | 0.2** | | |
| AXF | 4.2** | 3.0** | 2.0** | 1.2** | 1.2** | 1.0** | 0.8** | 0.6** | 0.6** | 0.4** | |
| AXM | 4.6** | 3.2** | 2.4** | 1.6** | 1.6** | 1.4** | 1.2** | 1.0** | 1.0** | 0.6** | 0.4** |

[a] Positive number indicates increase in spring nighttime surface temperature mean for the agricultural cover/soil type compared to that of the left-column agricultural cover/soil type. The agricultural cover/soil types are denoted as follows: ARC = row-crops on coastal sand, ARF = row-crops on flatwoods sand, ASM = pasture/sod on muck, AXR = mixed agriculture on sandy rockland, APR = pasture/range on sandy rockland, ACF = citrus orchard on flatwoods sand, ACS = citrus orchard on deep sand, AXL = mixed agriculture

Table 33--Continued.

on marly rockland, APF = pasture/range on flatwoods sand, ARL = row-crops on marly rockland, AXF = mixed agricultural on flatwoods sand, and AXM = mixed agriculture on muck. These cover/soil types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

highest difference in NST (4.6 C) was between row-crops on coastal sand and mixed agriculture on muck.

Soil type impacts on agricultural type temperatures were compared. Among the mixed agriculture combinations, the highest difference in NST (1.6 C) was between that on sandy rockland and that on muck. Differences between other mixed agriculture combinations were all significant and some were substantial. Among the row-crop combinations, the highest difference in mean NST (3.8 C) was between that on coastal sand and that on marly rockland; the differences between other row-crop combinations were also both significant and substantial. Among the pasture combinations, pasture/sod on muck had higher NST (by 1.0 C or more) than did pasture/range on either sandy rockland or flatwoods sand. Among the citrus orchard combinations, there was no significant difference between that on flatwoods sand and that on deep sand. In zone S in spring, the NST of certain agricultural types appears to be influenced by the soil type.

Agriculture type impacts on soil type temperatures were compared. Among the muck combinations, pasture/sod had higher NST (by 2.4 C) than did mixed agriculture. This was expected, since mixed agriculture includes more exposed soil, and is maintained under a lower water-table condition than is pasture. Among the sandy rockland combinations, there was no significant difference between mixed agriculture and pasture/range. Among the marly rockland combinations, there was no substantial difference between row-crops and mixed

agriculture. Among the flatwoods sand combinations, row-crops had higher NST (by 2.0 C or more) than did the other agricultural types. Citrus orchard had higher NST (by 1.0 C) than did mixed agriculture. There was no substantial difference between the other flatwoods sand agriculture types. In zone S in spring, the NST of certain soil types appears to be affected by the agricultural type.

Spring Nighttime Urban/Industrial Land-Cover Thermal Patterns

Zone P. Within zone P, there were two types of urban/industrial land cover, distributed on four soil types. Listed in order of decreasing mean NST (C), these included urban center on flatwoods sand (14.4), urban center on coastal sand (14.2), suburb on coastal sand (14.0), urban center on upland loamy sand (13.0), and urban center on deep sand (11.8). Differences in mean NST among zone P urban/industrial cover/soil type combinations are given in Table 34; most were significant, and many were substantial. Urban center on flatwoods sand had higher mean NST than did that on upland loamy sand (by 1.4 C) and that on deep sand (by 2.8 C), and that on upland loamy sand had higher NST (by 1.4 C) than did that on deep sand. There was no significant difference between urban center on coastal sand and suburb on coastal sand. The highest difference in NST (2.8 C) was between urban center on flatwoods sand and that on deep sand.

Zone N. Within zone N, there were six urban/industrial cover types present on five different soil types. Listed in

Table 34. Spring nighttime surface temperature differences among urban/industrial land-cover types in panhandle zone.

| Urban/indus. cover/soil type | Difference in NST (C) mean for urban/industrial cover/soil type[a] | | | |
|---|---|---|---|---|
| | UCF | UCC | USC | UCU |
| UCC | 0.2 | | | |
| USC | 0.4* | 0.4 | | |
| UCU | 1.4** | 1.2** | 0.8** | |
| UCS | 2.8** | 2.6** | 2.2** | 1.4** |

[a] Positive number indicates increase in spring nighttime surface temperature mean for the urban/industrial cover/soil type compared to that of the left-column urban/industrial cover/soil type. The urban/industrial cover/soil types are denoted as follows: UCF = urban center on flatwoods sand, UCC = urban center on coastal sand, USC = suburb on coastal sand, UCU = urban center on upland loamy sand, and UCS = urban center on deep sand. These cover/soil types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

order of decreasing mean NST (C), the combinations included golf-course suburb on flatwoods sand (16.4), suburb on coastal sand (16.4), urban center on flatwoods sand (14.6), urban center on deep sand (14.4), phosphate mine on flatwoods sand (14.0), suburb on sandy rockland (13.2), suburb on flatwoods sand (12.8), suburb on upland loamy sand (12.6), urban center on upland loamy sand (12.4), suburb on deep sand (11.6), titanium mine on deep sand (11.0), urban center on sandy rockland (11.0), and platted suburb on flatwoods sand (9.4). Differences in mean AST among zone N urban/industrial cover/soil type combinations are given in Table 35. Among these land cover types, the highest NST difference (7.0 C) was between golf-course suburb on flatwoods sand and platted suburb on flatwoods sand.

Soil type impacts on urban/industrial type temperatures were compared. Among the suburb combinations, the highest difference in mean NST (4.8 C) was between suburb on coastal sand and that on deep sand. Differences between suburbs on other soil types were smaller. Among the urban center combinations, there were substantial differences between soil types. Among the mine combinations, phosphate mine on flatwoods sand had a higher NST (by 3.0 C) than did titanium mine on deep sand, which can be attributed to the presence of settling ponds. In zone N in spring, soil type appears to have a substantial influence on the NST for most urban/industrial types.

Table 35. Spring nighttime surface temperature differences among urban/industrial land-cover types in north zone.

| Urban/ indus. cover/ soil type | Difference in NST (C) mean for urban/industrial cover/soil type[a] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | UGF | USC | UCF | UCS | UMF | USR | USF | USU | UCU | USS | UMS | UCR |
| USC | 0.0 | | | | | | | | | | | |
| UCF | 1.8$^{**}$ | 1.8$^{**}$ | | | | | | | | | | |
| UCS | 2.0$^{**}$ | 2.0$^{**}$ | 0.2 | | | | | | | | | |
| UMF | 2.4$^{**}$ | 2.4$^{**}$ | 0.6$^{**}$ | 0.4$^{**}$ | | | | | | | | |
| USR | 3.4$^{**}$ | 3.2$^{**}$ | 1.4$^{**}$ | 1.4$^{**}$ | 1.0$^{**}$ | | | | | | | |
| USF | 3.8$^{**}$ | 3.6$^{**}$ | 1.8$^{**}$ | 1.8$^{**}$ | 1.4$^{**}$ | 0.4$^{*}$ | | | | | | |
| USU | 4.0$^{**}$ | 3.8$^{**}$ | 2.0$^{**}$ | 2.0$^{**}$ | 1.6$^{**}$ | 0.6$^{**}$ | 0.2$^{*}$ | | | | | |
| UCU | 4.0$^{**}$ | 4.0$^{**}$ | 2.2$^{**}$ | 2.2$^{**}$ | 1.8$^{**}$ | 0.8$^{**}$ | 0.4$^{**}$ | 0.2$^{**}$ | | | | |
| USS | 4.8$^{**}$ | 4.8$^{**}$ | 3.0$^{**}$ | 2.8$^{**}$ | 2.4$^{**}$ | 1.4$^{**}$ | 1.0$^{**}$ | 0.8$^{**}$ | 0.6$^{**}$ | | | |
| UMS | 5.4$^{**}$ | 5.4$^{**}$ | 3.6$^{**}$ | 3.4$^{**}$ | 3.0$^{**}$ | 2.0$^{**}$ | 1.6$^{**}$ | 1.4$^{**}$ | 1.2$^{**}$ | 0.6$^{**}$ | | |
| UCR | 5.6$^{**}$ | 5.6$^{**}$ | 3.6$^{**}$ | 3.6$^{**}$ | 3.2$^{**}$ | 2.2$^{**}$ | 1.8$^{**}$ | 1.6$^{**}$ | 1.4$^{**}$ | 0.8$^{**}$ | 0.2 | |
| UPF | 7.0$^{**}$ | 7.0$^{**}$ | 5.2$^{**}$ | 5.0$^{**}$ | 4.6$^{**}$ | 3.6$^{**}$ | 3.2$^{**}$ | 3.0$^{**}$ | 2.8$^{**}$ | 2.2$^{**}$ | 1.6$^{**}$ | 1.4$^{**}$ |

[a] Positive number indicates increase in spring nighttime surface temperature mean for the urban/industrial cover/soil type compared to that of the left-column urban/industrial cover/soil type. The urban/industrial cover/soil types are denoted as follows: UGF =

Table 35--Continued.

golf-course suburb on flatwoods sand, USC = suburb on coastal sand, UCF = urban center on flatwoods sand, UCS = urban center on deep sand, UMF = phosphate mine on flatwoods sand, USR = suburb on sandy rockland, USF = suburb on flatwoods sand, USU = suburb on upland loamy sand, UCU = urban center on upland loamy sand, USS = suburb on deep sand, UMS = titanium mine on deep sand, UCR = urban center on sandy rockland, and UPF = platted suburb on flatwoods sand. These cover/soil types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Urban/industrial type impacts on soil type temperatures were compared. Among the deep sand combinations, urban center had higher NST than did suburb (by 2.8 C) or titanium mine (by 3.4 C). Among the rockland combinations, suburb had higher NST (by 2.2 C) than did urban center. Among the upland loamy sand combinations, there was no substantial difference between urban center and suburb. Among the flatwoods sand combinations, the highest difference in NST (7.0 C) was between golf-course suburb and platted suburb. Golf-course suburb had higher NST than did urban center (by 1.8 C), suburb (by 3.8 C), or phosphate mine (by 2.4 C). The high NST for golf-course suburb can be attributed to nighttime sprinkler irrigation. Urban center had higher NST (by 1.8 C) than did suburb. Phosphate mine had higher NST (by 1.4 C) than did suburb, which can be attributed to its tailings ponds. There was only one cover type present on coastal sand (suburb). In zone N in spring, most urban/industrial cover types had a substantial effect on the AST for a given soil type.

<ins>Zone S.</ins> Within zone S, there were five urban/industrial cover types present on up to five different soil types. Listed in order of decreasing NST (C) means, the combinations included finger-canal suburb on coastal sand (17.4), golf-course suburb on flatwoods sand (15.4), golf-course suburb on sandy rockland (15.0), finger-canal suburb on flatwoods sand (14.8), urban center on muck (14.8), urban center on flatwoods sand (14.8), urban center on sandy rockland (14.6), suburb on marly rockland (12.4), Indian reservation on flatwoods sand

(12.4), and suburb on flatwoods sand (12.4). Differences in mean NST among zone S urban/industrial cover/soil type combinations are given in Table 36; most were significant, and many were substantial. Among these land cover types, the highest NST difference (5.2 C) was between finger-canal suburb on coastal sand and suburb on flatwoods sand.

Soil type impacts on urban/industrial type temperatures were compared. There were no significant differences among the normal suburb types nor among the urban centers. In zone S in spring, soil type appears to have little effect on the NST for normal suburb and urban center cover types.

Urban/industrial type impacts on soil type temperatures were compared. Among the flatwoods sand combinations, Indian reservation and normal suburb had lower NST (by 2.4 C or more) than did the other suburb types and urban center, but this was the only substantial effect. It can be attributed to the moderating influences of the heat island for urban center, to nighttime irrigation for the golf-course suburb, and to the presence of water-bodies for the finger-canal suburb. In particular, the higher NST for golf-course suburb (by 2.8 C) than for Indian reservation is a strong indication of the effects of irrigation differences on these otherwise similar landscapes (sparse pavement, primarily a kilometer-scale mixture of grass with trees). Among the sandy rockland combinations, there was no substantial difference between urban center and golf-course suburb, which again indicates the high NST associated with golf-course suburb nighttime

Table 36. Spring nighttime surface temperature differences among urban/industrial land-cover types in south zone.

| Urban/ indus. cover/ soil type | Difference in NST (C) mean for urban/industrial cover/soil type[a] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | UFC | UGF | UGR | UFF | UCM | UCF | UCR | USL | URF |
| UGF | 2.2** | | | | | | | | |
| UGR | 2.4** | 0.2** | | | | | | | |
| UFF | 2.6** | 0.4** | 0.2 | | | | | | |
| UCM | 2.6** | 0.4** | 0.2 | 0.0 | | | | | |
| UCF | 2.6** | 0.6** | 0.4* | 0.0 | 0.0 | | | | |
| UCR | 2.8** | 0.6** | 0.4** | 0.2* | 0.2 | 0.2 | | | |
| USL | 5.0** | 2.8** | 2.6** | 2.4** | 2.4** | 2.2** | 2.2** | | |
| URF | 5.0** | 2.8** | 2.6** | 2.4** | 2.4** | 2.4** | 2.2** | 0.0 | |
| USF | 5.2** | 3.0** | 2.8** | 2.6** | 2.6** | 2.4** | 2.4** | 0.2 | 0.2 |

[a] Positive number indicates increase in spring nighttime surface temperature mean for the urban/industrial cover/soil type compared to that of the left-column urban/industrial cover/soil type. The urban/industrial cover/soil types are denoted as follows: UFC = finger-canal suburb on coastal sand, UGF = golf-course suburb on flatwoods sand, UGR = golf-course suburb on sandy rockland, UFF = finger-canal suburb on flatwoods sand, UCM = urban center on muck, UCF = urban center on flatwoods sand, UCR = urban center on sandy rockland, USL = suburb on marly rockland, URF = Indian reservation on flatwoods sand, and USF = suburb on flatwoods sand. These cover/soil types are further described in the text.

Table 36--Continued.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

irrigation. In zone S in spring, several urban/industrial cover types appear to have a substantial effect on the AST for a given soil type.

Spring Nighttime Change Analyses--Natural to Agricultural Land-Cover

Zone P. Differences in mean NST between zone P agricultural/soil type combinations and their original cover types are given in Table 37. There were no substantial differences in NST. Within zone P in spring, conversion from natural to mixed agriculture use appears to have no substantial effect on NST.

Zone N. Differences in mean NST between zone N agricultural/soil type combinations and their original cover types are given in Table 38. All of the agricultural types on flatwoods sand had higher NST (by 1.0 C or more) than did the flatwoods forest which was their original cover type; this reflects the relatively dry condition of flatwoods forest in the spring, as well as agricultural soil moisture levels maintained at that time. The higher difference from flatwoods forest NST for pasture/range than for citrus orchard can be attributed to the maintenance of a lower water table for citrus orchard. Citrus orchard had higher NST than did the original cover types on deep sand (by 1.8 C) and flatwoods sand (by 1.0 C), but there was no substantial increase in NST compared to original cover on upland loamy sand. The increased NST for citrus orchard can be attributed to

Table 37. Spring nighttime surface temperature change from natural to agricultural in panhandle zone.

| Soil type and natural cover | Difference in NST (C) mean for agricultural cover type[a] | |
|---|---|---|
| | Pasture/range | Mixed |
| Sand, deep (mixed scrub) | --- | 0.0 |
| Sand, loamy (upland mixed forest) | --- | 0.6** |
| Sand, flatwoods (flatwoods forest) | -0.4** | --- |

[a] Positive number indicates increase in spring nighttime surface temperature mean for agricultural cover type compared to that of the natural cover for the soil type.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Table 38. Spring nighttime surface temperature change from natural to agricultural in north zone.

| Soil type and natural cover | Difference in NST (C) mean for agricultural cover type[a] | | | | |
|---|---|---|---|---|---|
| | Row-crops | Pasture/ range | Pasture/ sod | Citrus orchard | Mixed |
| Sand, deep (mixed scrub) | --- | --- | --- | --- | -0.8** |
| Sand, deep (evergreen scrub) | --- | --- | --- | 1.8** | --- |
| Sand, loamy (upland mixed forest) | --- | --- | --- | 0.8** | -1.6** |
| Sand, flatwoods (flatwoods forest) | --- | 1.8** | --- | 1.0** | 2.6** |
| Rockland, sandy (calcareous hammock[b]) | --- | --- | --- | --- | -1.0** |
| Organic, muck (marsh) | -0.6** | --- | -1.8** | --- | --- |

[a] Positive number indicates increase in spring nighttime surface temperature mean for agricultural cover type compared to that of the natural cover for the soil type.

[b] Represented by upland mixed forest.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

irrigation. Muck soil agriculture types showed lower NST (by up to 1.8 C) than did the marsh which was their original cover; this can be attributed to drainage. The muck row-crops had less difference compared to marsh than did pasture/sod, which can be attributed to the maintenance of a higher water-table for row-crops than for grass. Similar drainage-related decreases in NST were observed for mixed agriculture on all soil types except flatwoods sand. In zone N in spring, conversion from natural to agricultural cover types appears to produce substantial effects on NST in many cases.

Zone S. Differences in mean AST between zone S agricultural/soil type combinations and their original cover types are given in Table 39. The situation on flatwoods soil is the reverse of that observed for zone N; the zone S agricultural types had lower NST than the flatwoods forest. This can be attributed to the relative zone S soil moisture differences between flatwoods forest and the levels maintained for agricultural types in spring. Muck soil agricultural types had much lower NST (by up to 6.2 C) than did the marsh which was their original cover; the higher NST difference from marsh for mixed agriculture than for pasture/sod can be attributed to the higher water-table maintained for pasture/sod. Citrus orchard on deep sand had higher NST (by 1.6 C) than did the evergreen scrub which was its original cover; this can be attributed to irrigation. In zone S in spring, conversion from natural to agricultural cover types

Table 39. Spring nighttime surface temperature change from natural to agricultural in south zone.

| Soil type and natural cover | Difference in NST (C) mean for agricultural cover type[a] | | | | |
|---|---|---|---|---|---|
| | Row-crops | Pasture/range | Pasture/sod | Citrus orchard | Mixed |
| Sand, deep (evergreen scrub) | --- | --- | --- | 1.6** | --- |
| Sand, flatwoods (flatwoods forest) | 0.0 | -2.2** | --- | -1.8** | -2.8** |
| Sand, coastal (coastal hammock) | 0.0 | --- | --- | --- | --- |
| Rockland, sandy (rockland hammock) | --- | 0.0 | --- | --- | 0.0 |
| Rockland, marly (rockland hammock) | -0.8** | --- | --- | --- | -0.6** |
| Organic, muck (marsh) | --- | --- | -3.8** | --- | -6.2** |

[a] Positive number indicates increase in spring nighttime surface temperature mean for agricultural cover type compared to that of the natural cover for the soil type.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

appears to substantially affect NST on most soil types (except sandy and marly rockland).

## Spring Nighttime Change Analyses--Natural to Urban/Industrial Land-Cover

Zone P. Differences in mean NST between zone P urban/ industrial cover/soil type combinations and their original cover types are given in Table 40. Among the coastal sand types, both suburb and urban center had lower NST (by 1.6 C or more) than did the coastal hammock which was their original cover. Urban heat-island effects of substantially higher NST were observed for urban center on upland loamy sand and flatwoods sand, but not on deep sand. Within zone P in spring, conversion from natural to urban use produces substantial effects for most soil types.

Zone N. Differences in mean NST between zone N urban/ industrial cover/soil type combinations and their original cover types are given in Table 41. Among the flatwoods sand urban/industrial types, NST was substantially increased compared to flatwoods forest for all types (except platted suburb). The largest NST increase on flatwoods sand was for golf-course suburb, which can be attributed to nighttime irrigation. The decrease in NST for platted suburb compared to original cover can be attributed to its characteristics--cleared land with few houses and little irrigation. Suburb types generally had higher NST than did their original cover types for most soils (except sandy rockland and deep sand).

Table 40. Spring nighttime surface temperature change from natural to urban/industrial in panhandle zone.

| | Difference in NST (C) mean for urban/industrial cover type[a] | |
|---|---|---|
| Soil type and natural cover | Suburb | Urban center |
| Sand, deep (mixed scrub) | --- | 0.6** |
| Sand, loamy (upland mixed forest) | --- | 2.2** |
| Sand, flatwoods (flatwoods forest) | --- | 3.2** |
| Sand, coastal (coastal hammock) | -1.8** | -1.6** |

[a] Positive number indicates increase in spring nighttime surface temperature mean for urban/industrial cover type compared to that of the natural cover for the soil type.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Table 41. Spring nighttime surface temperature change from natural to urban/industrial in north zone.

| Soil type and natural cover | Difference in NST (C) mean for urban/industrial cover type[a] | | | | | |
|---|---|---|---|---|---|---|
| | Suburb | Platted suburb | Golf-course suburb | Urban center | Phos. mine | Titan. mine |
| Sand, deep (mixed scrub) | --- | --- | --- | --- | --- | -0.4** |
| Sand, deep (evergreen scrub) | 0.2** | --- | --- | 3.2** | --- | --- |
| Sand, loamy (upland mixed forest) | 1.2** | --- | --- | 1.0** | --- | --- |
| Sand, flatwoods (flatwoods forest) | 2.0** | -1.2** | 5.8** | 3.8** | 3.4** | --- |
| Sand, coastal (coastal hammock) | 2.2** | --- | --- | --- | --- | --- |
| Rockland, sandy (rockland hammock) | -0.2 | --- | --- | --- | --- | --- |
| Rockland, sandy (calcareous hammock[b]) | --- | --- | --- | -0.4** | --- | --- |

Table 41--Continued.

[a] Positive number indicates increase in spring nighttime surface temperature mean for urban/industrial cover type compared to that of the natural cover for the soil type.

[b] Represented by upland mixed forest.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Urban heat-island effects were observed in the form of substantially higher NST compared to original cover for all soils (except sandy rockland). Among the mine types, phosphate mine showed a substantially higher NST than its original cover, while titanium mine did not. In zone N in spring, changes from natural to urban/industrial cover type produced substantial changes in NST in many cases.

Zone S. Differences in mean NST between zone S urban/industrial soil type combinations and their original cover types are given in Table 42. Suburb and golf-course suburb had higher NST than did their original cover types; this is attributable to nighttime irrigation. Indian reservation had lower NST (by 2.4 C) than did the flatwoods forest which was its original cover, while golf-course suburb was not substantially different from flatwoods forest; these differences serve as an indication of the impact of irrigation on otherwise similar landscapes. Urban heat-island effects of higher NST for urban center than for original cover were noted for sandy rockland, but not for flatwoods sand or muck. In fact, urban center on muck had lower NST (by 3.0 C) than did the marsh which was its original cover. In zone S in spring, conversion from natural to urban cover types produced substantial changes in NST in many cases.

Table 42. Spring nighttime surface temperature change from natural to urban/industrial in south zone.

| Soil type and natural cover | Difference in NST (C) mean for urban/industrial cover type[a] | | | | |
|---|---|---|---|---|---|
| | Suburb | Finger-canal suburb | Golf-course suburb | Indian reserv. | Urban center |
| Sand, flatwoods (flatwoods forest) | 2.6** | 0.0 | 0.4** | -2.4** | 0.0 |
| Sand, coastal (coastal hammock) | --- | 1.2** | --- | --- | --- |
| Rockland, sandy (rockland hammock) | --- | --- | 1.8** | --- | 1.4** |
| Rockland, marly (rockland hammock) | -0.8** | --- | --- | --- | --- |
| Organic, muck (marsh) | --- | --- | --- | --- | -3.0** |

[a] Positive number indicates increase in spring nighttime surface temperature mean for urban/industrial cover type compared to that of the natural cover for the soil type.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Spring Nighttime Change Analyses--Agricultural to Urban/ Industrial Land-Cover.

Zone P. Differences in mean NST between zone P urban/industrial cover/soil type combinations and their agricultural counterparts are given in Table 43. Heat-island effects of substantial increases in NST compared to agricultural cover type were observed for urban centers on upland loamy sand and flatwoods sand, but not for deep sand. Within zone P in spring, conversion from agricultural to urban center use generally appears to increase NST.

Zone N. Differences in mean NST between zone N urban/industrial cover/soil type combinations and their agricultural counterparts are given in Table 44. The largest increases in NST (up to 4.6 C) compared to agricultural cover were observed for golf-course suburb; this is attributable to nighttime irrigation. Normal suburb differences from agricultural cover showed more variation. Platted suburb had substantially lower NST (by up to 3.8 C) than did agricultural types on flatwoods sand. Heat-island effects of increased NST compared to agricultural cover were observed for most agricultural types. Among the mine types, phosphate mine had higher NST compared to agricultural cover, while titanium mine had lower NST compared to agricultural cover. These differences can be attributed to the effects of settling ponds in phosphate mine. In zone N in spring, conversion of agriculture to urban/industrial cover appears to substantially affect the NST in many cases.

Table 43. Spring nighttime surface temperature change from agricultural to urban/industrial in panhandle zone.

| Soil type and agric. cover | Difference in NST (C) mean for urban/industrial cover type[a]: Urban center |
|---|---|
| Sand, deep (mixed agric.) | 0.6** |
| Sand, loamy (mixed agric.) | 1.6** |
| Sand, flatwoods (pasture/ range) | 3.6** |

[a] Positive number indicates increase in spring nighttime surface temperature mean for urban/industrial cover type compared to that of the agricultural cover for the soil type.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Table 44. Spring nighttime surface temperature change from agricultural to urban/industrial in north zone.

| Soil type and agric. cover | Difference in NST (C) mean for urban/industrial cover type[a] | | | | | |
|---|---|---|---|---|---|---|
| | Suburb | Platted suburb | Golf-course suburb | Urban center | Phos. mine | Tita. mine |
| Sand, deep (citrus orchard) | $-1.6^{*}$ | --- | --- | $1.2^{**}$ | --- | $-2.2^{**}$ |
| Sand, deep (mixed agric.) | $0.8^{**}$ | --- | --- | $3.6^{**}$ | --- | $0.4^{*}$ |
| Sand, loamy (citrus orchard) | $0.4^{**}$ | --- | --- | $0.2^{**}$ | --- | --- |
| Sand, loamy (mixed agric.) | $2.6^{**}$ | --- | --- | $2.4^{**}$ | --- | --- |
| Sand, flatwoods (pasture/range) | $0.2^{**}$ | $-3.0^{**}$ | $4.0^{**}$ | $2.2^{**}$ | $1.6^{**}$ | --- |
| Sand, flatwoods (citrus orchard) | $1.0^{**}$ | $-2.4^{**}$ | $4.6^{**}$ | $2.8^{**}$ | $2.4^{**}$ | --- |
| Sand, flatwoods (mixed agric.) | $-0.6^{**}$ | $-3.8^{**}$ | $3.2^{**}$ | $1.2^{**}$ | $0.8^{**}$ | --- |
| Rockland, sandy (mixed agric.) | --- | --- | --- | $0.6^{**}$ | --- | --- |

Table 44--Continued.

[a] Positive number indicates increase in spring nighttime surface temperature mean for urban/industrial cover type compared to that of the agricultural cover for the soil type.

[*] Significant at $\alpha = 0.05$.

[**] Significant at $\alpha = 0.01$.

Zone S. Differences in mean NST between zone S urban/industrial cover/soil type combinations and their agricultural counterparts are given in Table 45. The largest increases in NST (by up to 3.2 C) were observed for golf-course suburbs compared to agricultural cover; this is attributable to nighttime irrigation. Finger-canal suburbs also had higher NST (by up to 2.8 C) than did agricultural cover types; this is attributable to their large fraction of water-body surface. Normal suburbs and Indian reservation had generally little effect on NST compared to agricultural types (except for row-crops on flatwoods sand). The stronger NST change compared to agricultural cover for golf-course suburb than for Indian reservation serves as an indication of the effect of irrigation. Heat-island effects in the form of increased NST compared to agricultural cover were observed for most urban centers. In zone S in spring, conversion from agricultural to urban cover types appears to substantially affect NST in many cases.

## Spring Nighttime Comparison of Agricultural to Natural Cold Islands

Zone P. Differences in mean NST between agricultural cover types and the coldest natural feature of zone P (upland mixed forest) are given in Table 46. There was no substantial difference in NST between the coldest natural feature and mixed agriculture on deep sand and upland loamy sand, or pasture/range on flatwoods sand. All of the agricultural

Table 45. Spring nighttime surface temperature change from agricultural to urban/industrial in south zone.

| Soil type | Difference in NST (C) mean for urban/industrial cover type[a] | | | | |
|---|---|---|---|---|---|
| | Suburb | Finger-canal suburb | Golf-course suburb | Indian reserv. | Urban center |
| Sand, flatwoods (row-crops) | -2.6** | 0.0 | 0.4** | -2.4** | -0.2 |
| Sand, flatwoods (pasture/range) | -0.2** | 2.2** | 2.6** | -0.2** | 2.2** |
| Sand, flatwoods (citrus orchard) | -0.6** | 1.8** | 2.2** | -0.6** | 1.8** |
| Sand, flatwoods (mixed agric.) | 0.4** | 2.8** | 3.2** | 0.4** | 2.8** |
| Sand, coastal (row-crops) | --- | 1.2** | --- | --- | --- |
| Rockland, sandy (pasture/range) | --- | --- | 1.8** | --- | 1.4** |
| Rockland, sandy (mixed agric.) | --- | --- | 1.8** | --- | 1.4** |
| Rockland, marly (row-crops) | 0.2 | --- | --- | --- | --- |
| Rockland, marly (mixed agric.) | -0.2 | --- | --- | --- | --- |
| Organic, muck (pasture/sod) | --- | --- | --- | --- | 0.8** |
| Organic, muck (mixed agric.) | --- | --- | --- | --- | 3.2** |

[a] Positive number indicates increase in spring nighttime surface temperature mean for urban/industrial cover type compared to that of the agricultural cover for the soil type.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Table 46. Spring nighttime surface temperature of agricultural land-cover types vs coldest natural land-cover.

| | Difference in NST (C) mean for agricultural cover type[a] | | | | |
|---|---|---|---|---|---|
| Soil type | Row-crops | Pasture/ range | Pasture/ sod | Citrus orchard | Mixed |
| Zone P | | | | | |
| Sand, deep | --- | --- | --- | --- | 0.2** |
| Sand, loamy | --- | --- | --- | --- | 0.6** |
| Sand, flatwoods | --- | -0.2** | --- | --- | --- |
| Zone N | | | | | |
| Sand, deep | --- | --- | --- | 2.4** | 0.0 |
| Sand, loamy | --- | --- | --- | 1.4** | -0.8** |
| Sand, flatwoods | --- | 1.8** | --- | 1.0** | 2.6** |
| Rockland, sandy | --- | --- | --- | --- | -0.4** |
| Organic, muck | 2.6** | --- | 1.4** | --- | --- |
| Zone S | | | | | |
| Sand, deep | --- | --- | --- | 1.6** | --- |
| Sand, flatwoods | 3.6** | 1.4** | --- | 1.8** | 0.8** |
| Sand, coastal | 5.0** | --- | --- | --- | --- |
| Rockland, sandy | --- | 2.0** | --- | --- | 2.0** |
| Rockland, marly | 1.0** | --- | --- | --- | 1.4** |
| Organic, muck | --- | --- | 2.8** | --- | 0.4* |

[a] Positive number indicates increase in spring nighttime surface temperature mean for agricultural cover type compared to that of coldest natural cover type (upland mixed forest in zone P, flatwoods forest in zone N, evergreen scrub in zone S).

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

types produced cold-island effects matching the NST of the coldest natural feature. No agricultural cold-island effects with substantially lower NST than the coldest natural feature were observed.

Zone N. Differences in mean NST between agricultural cover types and the coldest natural feature of zone N (flatwoods forest) are given in Table 46. There was no substantial difference between the NST of the coldest natural feature and that of mixed agriculture on deep sand, flatwoods sand, and sandy rockland. These three cold-island effects matched the NST of the coldest natural feature. No agricultural cold-island effects with substantially lower NST than the coldest natural feature were observed.

Zone S. Differences in mean NST between agricultural cover types and the coldest natural feature of zone S (evergreen scrub) are given in Table 46. There was no substantial difference between the NST of the coldest natural feature and that of mixed agriculture on flatwoods sand or muck. These two cold-island effects matched the NST of the coldest natural feature. No agricultural cold-island effects with substantially lower NST than the coldest natural feature were observed.

## Spring Nighttime Comparison of Urban/Industrial to Natural Cold Islands

Zone P. Differences in mean NST between urban/industrial cover types and the coldest natural feature of zone P (upland

mixed forest) are given in Table 47. There was no difference in NST between the coldest natural feature and urban center on deep sand. This cold-island effect matched the NST of the coldest natural feature. No urban cold-island effects with substantially lower NST than the coldest natural feature were observed.

Zone N. Differences in mean NST between urban/industrial cover types and the coldest natural feature of zone N (flatwoods forest) are given in Table 47. There was no substantial difference in NST between the coldest natural feature and urban center on sandy rockland or titanium mine on deep sand. These two cold-island effects matched the NST of the coldest natural feature. Platted suburb had lower NST (by 1.2 C) than did the coldest natural feature; this can be attributed to its characteristics--cleared land with little pavement and no irrigation.

Zone S. Differences in mean NST between urban/industrial cover types and the hottest natural feature of zone S (evergreen scrub on deep sand) are given in Table 47. No substantial urban cold-island effects were observed.

## Spring Nighttime Change Analyses--Special Factors

Natural factors. Normal and droughty natural land-cover types were compared. As shown in Table 48, droughty bay swamp (mean 10.4 C) had lower NST (by 4.8 C) than did normal bay swamp. Droughty mixed swamp (mean 10.0 C) had lower NST (by 2.4 C) than did normal mixed swamp. The greater drought-

Table 47. Spring nighttime surface temperature of urban/industrial land-cover types vs coldest natural land-cover.

| Soil type | Difference in NST (C) mean for urban/industrial cover type[a] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Suburb | Platted suburb | Finger-canal suburb | Golf-course suburb | Indian reserv. | Urban center | Phos. mine | Tita. mine |
| Zone P | | | | | | | | |
| Sand, deep | --- | --- | --- | --- | --- | 0.8** | --- | --- |
| Sand, loamy | --- | --- | --- | --- | --- | 2.2** | --- | --- |
| Sand, flatwoods | --- | --- | --- | --- | --- | 3.4** | --- | --- |
| Sand, coastal | 3.0** | --- | --- | --- | --- | 3.2** | --- | --- |
| Zone N | | | | | | | | |
| Sand, deep | 1.0** | --- | --- | --- | --- | 3.8** | --- | 0.4** |
| Sand, loamy | 1.8** | --- | --- | --- | --- | 1.6** | --- | --- |
| Sand, flatwoods | 2.0** | -1.2** | --- | 5.8** | --- | 3.8** | 3.4** | --- |
| Sand, coastal | 5.6** | --- | --- | --- | --- | --- | --- | --- |
| Rockland, sandy | 2.4** | --- | --- | --- | --- | 0.2* | --- | --- |

Table 47--Continued.

| Soil type | Difference in NST (C) mean for urban/industrial cover type[a] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Suburb | Platted suburb | Finger-canal suburb | Golf-course suburb | Indian reserv. | Urban center | Phos. mine | Tita. mine |
| Zone S | | | | | | | | |
| Sand, flatwoods | 1.0** | --- | 3.6** | 4.0** | 1.2** | 3.4** | --- | --- |
| Sand, coastal | --- | --- | 6.2** | --- | --- | --- | --- | --- |
| Rockland, sandy | --- | --- | --- | 3.8** | --- | 3.4** | --- | --- |
| Rockland, marly | 1.2** | --- | --- | --- | --- | --- | --- | --- |
| Organic, muck | --- | --- | --- | --- | --- | 3.6** | --- | --- |

[a] Positive number indicates increase in spring nighttime surface temperature mean for urban/industrial cover type compared to that of coldest natural cover type (upland mixed forest in zone P, flatwoods forest in zone N, evergreen scrub in zone S).

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Table 48. Spring nighttime surface temperature change for special conditions.

| Zone | Difference in NST (C) mean for cover type under special condition[a] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Bay swamp[b] | Mixed swamp[c] | Citrus orchard[d] | Urban center[e] | Cypress swamp[f] | Marsh[g] | Marsh[h] | Flatwoods forest[i] |
| N | -4.8** | -2.4** | -0.2* | --- | --- | --- | --- | --- |
| S | --- | --- | --- | -2.0** | -4.0** | -5.0** | -2.4** | -0.8** |

[a] Positive number indicates increase in spring nighttime surface temperature mean for cover type under special condition compared to that of the cover type under normal condition.

[b] Bay swamps under drought condition in north-central Florida (Sandlin Bay and Little Santa Fe Lake area) compared to those under normal condition in central Florida (Chassahowitzka Swamp). See also Mixed Swamp note below.

[c] Mixed swamps under drought condition in north-central Florida and south Georgia (Okeefenokee N.W.R. south of Suwannee R., Pinhook Swamp) compared to those under normal condition in other areas (Okeefenokee N.W.R. north of Suwannee R., Withlacoochee State Forest southeast, Devils Hammock, Hull Cypress Swamp/Bennett Swamp, Spruce Creek Swamp, and Wekiva Swamp). The Okeefenokee N.W.R. hydrology is controlled by a system of dikes and canals along the Suwannee R. Wildfire broke out in the drought-stricken mixed swamp area two months (June 1993) after this image (April 1993).

[d] Citrus orchard (on deep sand) in area heavily damaged by freezes of mid 1980s (Okahumpka/Clermont area) compared to citrus orchard (on deep sand) in areas which had quickly recovered (Ft. Meade, east area and Lake Wales area).

[e] Urban center (Homestead/Leisure City area) on sandy rockland under heavily damaged condition--eight months (April 1993) after Hurricane Andrew (August 1992), compared to nearby urban center on sandy rockland under normal condition (Ft. Lauderdale/Miami).

Table 48--Continued.

[f] Disturbed dwarf-cypress swamp in abandoned platted subdivision (Golden Gate Estates, east area) compared to normal dwarf-cypress swamps nearby (Big Cypress National Preserve--central, southeast, and southwest).

[g] Marsh within the EAA canal system (Holey Land/Rotenberger Wildlife Management Areas) compared to marsh in less-impacted areas (Moonshine Bay area of Lake Okeechobee, Water Conservation Area 2, and Little Doctor Village/Custard Apple Hammock area of the deep Everglades).

[h] Marsh within an area heavily impacted by EAA drainage system (Water Conservation Area 1) compared to marsh in less-impacted areas (Moonshine Bay area of Lake Okeechobee, Water Conservation Area 2, and Little Doctor Village/Custard Apple Hammock area of the deep Everglades).

[i] Flatwoods forest (on flatwoods sand) in West Green Acres area invaded by exotic forest, compared to normal flatwoods forest in other areas (Gator Slough, C. M. Webb WMA, J. W. Corbett WMA, Keri area, and Rainey Slough).

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

related decrease in NST for bay swamp than for mixed swamp can be attributed to the organic soil of bay swamp.

Freeze-damaged and normal citrus orchard land-cover were compared. As shown on Table 48, the difference in NST between freeze-damaged citrus orchard on deep sand and normal citrus orchard on deep sand was significant, but not substantial. The slight decrease in NST for the damaged area may be attributed to the loss of tree canopy on abandoned groves, to decreased canopy on groves converted to pine plantations (very young at image date) and vineyards, and especially to cessation of irrigation.

Hurricane-damaged and normal urban/industrial land-cover types were compared. As shown in Table 48, hurricane-damaged urban center on sandy rockland (mean 12.8 C) had lower NST (by 2.0 C) than did normal urban center on sandy rockland. This dramatic loss of the urban heat-island effect can be attributed to the decrease in the fractional areal occupied by roof-tops after the hurricane (vegetation cover had already returned to the area), as well as the cessation of irrigation.

<u>Artificial factors.</u> Disturbed and normal dwarf-cypress land-cover types were compared. As shown in Table 48, the disturbed dwarf cypress swamp (mean 11.0 C) had much lower NST (by 4.0 C) than did normal dwarf cypress swamp.

Disturbed and normal marsh land-cover types were compared. As shown in Table 48, the Holey Land/Rotenburger Wildlife Management Area of the EAA (mean 13.0 C) had much lower NST (by 5.0 C) than did normal marsh. As shown in Table

48, marsh within the Water Conservation Area 1 (mean 15.4 C) had lower NST (by 2.4 C) than did normal marsh. These findings for disturbed wetlands indicate that major disturbances (widespread change in vegetation species composition accompanied by/related to major hydrologic alteration) of natural communities appear to decrease NST.

Exotic forest and normal flatwoods forest land-cover types were compared. As shown in Table 48, the difference in NST between exotic forest (mean 14.0 C) and normal flatwoods forest was significant, but not substantial.

## Spring Diurnal Natural Land-Cover Thermal Patterns

Zone P. Within zone P in spring, eight natural land cover types were present. Listed in order of decreasing mean DSTV (C), these included mixed scrub (16.2), upland mixed forest (15.8), flatwoods forest (14.8), marsh (11.2), bay swamp (11.2), deciduous hardwood swamp (8.4), saltmarsh (8.0), and coastal hammock (7.0). Differences in mean DSTV among zone P natural land cover types are given in Table 49; most were significant, and many were substantial. The highest difference (9.0 C) was between mixed scrub and coastal hammock. The overall trend was a higher DSTV for the drier natural land-cover types (mixed scrub, upland mixed forest), and lower DSTV for the wetter types (marshes and swamps).

Zone N. Within zone N in spring, thirteen natural land cover types were present. Listed in order of decreasing mean DSTV (C), these included mixed scrub (17.0), evergreen scrub

Table 49. Spring diurnal surface temperature variation differences among natural land-cover types in panhandle zone.

| Natural cover type | Difference in DSTV (C) mean for natural cover type[a] | | | | | | |
|---|---|---|---|---|---|---|---|
| | SCM | FMX | FLW | MRF | SBY | SHD | MRS |
| FMX | 0.2** | | | | | | |
| FLW | 1.4** | 1.2** | | | | | |
| MRF | 4.8** | 4.6** | 3.4** | | | | |
| SBY | 4.8** | 4.6** | 3.4** | 0.0 | | | |
| SHD | 7.8** | 7.4** | 6.4** | 3.0** | 2.8** | | |
| MRS | 8.2** | 8.0** | 6.8** | 3.4** | 3.4** | 0.4** | |
| HCO | 9.0** | 8.8** | 7.6** | 4.2** | 4.2** | 1.2** | 0.8** |

[a] Positive number indicates increase in spring diurnal surface temperature variation mean for the natural cover type compared to that of the left-column natural cover type. The natural cover types are denoted as follows: SCM = mixed scrub, FMX = upland mixed forest, FLW = flatwoods forest, MRF = marsh, SBY = bay swamp, SHD = deciduous hardwood swamp, MRS = saltmarsh, and HCO = coastal hammock. These natural cover types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

(16.6), flatwoods forest (15.6), upland mixed forest (15.0), evergreen hardwood swamp (13.8), mixed swamp (13.4), deciduous hardwood swamp (13.2), cypress swamp (13.0), marsh (12.0), rockland hammock (10.6), coastal hammock (9.6), bay swamp (8.8), and saltmarsh (8.0). Differences in mean DSTV among zone N natural land cover types are given in Table 50; most were significant, and many were substantial. Among these natural land cover types, the highest difference (9.0 C) in DSTV was between mixed scrub and saltmarsh. The overall trend was a higher DSTV for the drier natural land-cover types (mixed scrub, evergreen scrub), and lower DSTV for the wetter types (marshes and swamps). Differences between evergreen and deciduous subtypes of scrub and hardwood swamp were significant, but not substantial--as expected from a spring date (deciduous subtypes in full foliage).

Zone S. Within zone S in spring, fourteen natural land cover types were present. Listed in order of decreasing mean DSTV (C), these included evergreen scrub (18.2), rockland hammock (14.4), flatwoods forest (12.4), mixed swamp (12.4), evergreen shrubby marsh (12.2), wet-prairie (12.0), deciduous shrubby marsh (11.8), brackish marsh (11.6), dwarf cypress swamp (11.6), evergreen hardwood swamp (11.2), cypress swamp (10.8), mangrove swamp (9.4), marsh (8.4), and coastal hammock (8.4). Differences in mean DSTV among zone S natural land cover types are given in Table 51; most were significant, and many were substantial. Among these natural land cover types, the highest difference (10.0 C) in DSTV was between evergreen

Table 50. Spring diurnal surface temperature variation differences among natural land-cover types in north zone.

| Natural cover type | Difference in DSTV (C) mean for natural cover type[a] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SCM | SCE | FLW | FMX | SHE | SMX | SHD | SCY | MRF | HRO | HCO | SBY |
| SCE | 0.4** | | | | | | | | | | | |
| FLW | 1.4** | 4.4** | | | | | | | | | | |
| FMX | 2.0** | 1.6** | 0.6** | | | | | | | | | |
| SHE | 3.2** | 2.6** | 1.8** | 1.2** | | | | | | | | |
| SMX | 3.6** | 3.2** | 2.4** | 1.6* | 0.4** | | | | | | | |
| SHD | 3.8** | 3.4** | 2.6** | 1.8** | 0.8** | 0.2** | | | | | | |
| SCY | 4.0** | 3.4** | 2.6** | 2.0** | 0.8** | 0.4** | 0.2 | | | | | |
| MRF | 5.0** | 4.6** | 3.6** | 3.0** | 1.8** | 1.4** | 1.2** | 1.0** | | | | |
| HRO | 6.4** | 6.0** | 5.0** | 4.4** | 3.2** | 2.8** | 2.6** | 2.4** | 1.0** | | | |
| HCO | 7.4** | 7.0** | 6.0** | 5.4** | 4.2** | 3.8** | 3.6** | 3.4** | 1.8** | 1.0** | | |
| SBY | 8.2** | 7.8** | 7.0** | 6.2** | 5.2** | 4.6** | 4.4** | 4.4** | 3.4** | 1.8** | 1.0** | |
| MRS | 9.0** | 8.6** | 7.6** | 7.0** | 5.8** | 5.4** | 5.2** | 5.0** | 4.0** | 2.6** | 1.6** | 0.8** |

[a] Positive number indicates increase in spring diurnal surface temperature variation mean for the natural cover type compared to that of the left-column natural cover type. The natural cover types are denoted as follows: SCM = mixed scrub, SCE = evergreen scrub, FLW = flatwoods forest, FMX = upland mixed forest, SHE = evergreen hardwood swamp, SMX

Table 50--Continued.

= mixed swamp, SHD = deciduous hardwood swamp, SCY = cypress swamp, MRF = marsh, HRO = rockland hammock, HCO = coastal hammock, SBY = bay swamp, and MRS = saltmarsh. These natural cover types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Table 51. Spring diurnal surface temperature variation differences among natural land-cover types in south zone.

| Nat. cov. type | Difference in DSTV (C) mean for natural cover type[a] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SCE | HRO | FLW | SMX | MSE | MRP | MSD | MRS | SCD | SHE | SCY | SMG | MRF |
| HRO | 3.8** | | | | | | | | | | | | |
| FLW | 5.8** | 2.0** | | | | | | | | | | | |
| SMX | 6.0** | 2.2** | 0.2* | | | | | | | | | | |
| MSE | 6.0** | 2.2** | 0.4 | 0.2 | | | | | | | | | |
| MRP | 6.2** | 2.4** | 0.6** | 0.4* | 0.2 | | | | | | | | |
| MSD | 6.6** | 2.8** | 0.8** | 0.6** | 0.4 | 0.2 | | | | | | | |
| MRS | 6.6** | 2.8** | 0.8** | 0.6** | 0.4 | 0.2 | 0.0 | | | | | | |
| SCD | 6.8** | 2.8** | 1.0** | 0.8** | 0.6* | 0.4* | 0.2 | 0.2 | | | | | |
| SHE | 7.0** | 3.2** | 1.2** | 1.0** | 1.0** | 0.8** | 0.4* | 0.4** | 0.2** | | | | |
| SCY | 7.6** | 3.8** | 1.8** | 1.6** | 1.4** | 1.2** | 1.0** | 1.0** | 0.8** | 0.6** | | | |
| SMG | 9.0** | 5.2** | 3.2** | 3.0** | 2.8** | 2.6** | 2.4** | 2.4** | 2.2** | 2.0** | 1.4** | | |
| MRF | 9.8** | 6.0** | 4.2** | 4.0** | 3.8** | 3.6** | 3.4** | 3.4** | 3.2** | 3.0** | 2.4** | 1.0** | |
| HCO | 10.0** | 6.0** | 4.2** | 4.0** | 3.8** | 3.6** | 3.4** | 3.4** | 3.2** | 3.0** | 2.4** | 1.0** | 0.0 |

[a] Positive number indicates increase in spring diurnal surface temperature variation mean for the natural cover type compared to that of the left-column natural cover type. The

Table 51--Continued.

natural cover types are denoted as follows: SCE = evergreen scrub, HRO = rockland hammock, FLW = flatwoods forest, SMX = mixed swamp, MSE = evergreen shrubby marsh, MRP = wet-prairie, MSD = deciduous shrubby marsh, MRS = saltmarsh, SCD = dwarf cypress swamp, SHE = evergreen hardwood swamp, SCY = cypress swamp, SMG = mangrove swamp, MRF = marsh, and HCO = coastal hammock. These natural cover types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

scrub and coastal hammock. The overall trend was a higher DSTV for the drier natural land-cover types (evergreen scrub), and lower DSTV for the wetter types (marshes and swamps). The relatively high DSTV of wet-prairie and brackish marsh (both on marly rockland soil) reflects their April dry-season hydrology; the marsh subtype (on muck soil) remains wet throughout the year. There was no substantial difference in DSTV between evergreen and deciduous subtypes of shrubby marsh. There was no substantial difference in DSTV between dwarf-cypress swamp and cypress swamp.

## Spring Diurnal Agricultural Land-Cover Thermal Patterns

Zone P. Within zone P, there were two types of agriculture distributed on three soil types. Listed in order of decreasing mean DSTV (C), these agricultural/soil type combinations included mixed agriculture on deep sand (18.2), mixed agriculture on upland loamy sand (16.2), and pasture/range on flatwoods sand (14.2). Differences in mean DSTV among zone P agricultural/soil type combinations are given in Table 52; all were both significant and substantial. The highest difference in DSTV (4.0 C) was between mixed agriculture on deep sand and pasture/range on flatwoods sand. Mixed agriculture on deep sand had higher DSTV (by 2.0 C) than did that on upland loamy sand.

Zone N. Within zone N in spring, there were five agriculture types on up to five different soil types. Listed in order of decreasing mean DSTV (C), these combinations

Table 52. Spring diurnal surface temperature variation differences among agricultural land-cover types in panhandle zone.

| Agricultural cover/soil type | Difference in DSTV (C) mean for agricultural cover/soil type[a] | |
|---|---|---|
| | AXS | AXU |
| AXU | 2.0** | |
| APF | 4.0** | 2.0** |

[a] Positive number indicates increase in spring diurnal surface temperature variation mean for the agricultural cover/soil type compared to that of the left-column agricultural cover/soil type. The agricultural cover/soil types are denoted as follows: AXS = mixed agriculture on deep sand, AXU = mixed agriculture on upland loamy sand, and APF = pasture/range on flatwoods sand. These cover/soil types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

included mixed agriculture on upland loamy sand (19.4), mixed agriculture on deep sand (18.6), mixed agriculture on sandy rockland (18.4), citrus orchard on upland loamy sand (17.2), citrus orchard on deep sand (16.2), citrus orchard on flatwoods sand (16.0), row-crops on muck (15.6), pasture/sod on muck (15.4), pasture/range on flatwoods sand (14.6), and mixed agriculture on flatwoods sand (13.2). Differences in mean DSTV among zone N agricultural/soil type combinations are given in Table 53; most were significant, and many were substantial. Among these agricultural land cover types, the highest difference in DSTV (6.2 C) was between mixed agriculture on upland loamy sand and mixed agriculture on flatwoods sand.

Soil type impacts on agricultural type temperatures were compared. Among the mixed agriculture combinations, that on flatwoods sand had lower DSTV than that on other soil types. Mixed agriculture on upland loamy sand had higher DSTV (by 1.0 C) than did that on sandy rockland. Other differences between mixed agriculture types were significant, but not substantial. Among the pasture combinations, the difference in DSTV between pasture/sod on muck and pasture/range on flatwoods sand was significant, but not substantial. Among the citrus orchard combinations, that on upland loamy sand had higher DSTV than did that on either deep sand or flatwoods sand. There was no significant difference in DSTV between citrus orchard on deep sand and that on flatwoods sand. In zone N in spring, upland loamy sand appears to increase the DSTV of a given

Table 53. Spring diurnal surface temperature variation differences among agricultural land-cover types in north zone.

| Agric. cover/ soil type | Difference in DSTV (C) mean for agricultural cover/soil type[a] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | AXU | AXS | AXR | ACU | ACS | ACF | ARM | ASM | APF |
| AXS | 0.8** | | | | | | | | |
| AXR | 1.0** | 0.2** | | | | | | | |
| ACU | 2.2** | 1.4** | 1.2** | | | | | | |
| ACS | 3.2** | 2.6** | 2.2** | 1.0** | | | | | |
| ACF | 3.4** | 2.6** | 2.4** | 1.2** | 0.2 | | | | |
| ARM | 3.8** | 3.2** | 2.8** | 1.6** | 0.6* | 0.4 | | | |
| ASM | 4.0** | 3.2** | 3.0** | 1.8** | 0.8** | 0.6** | 0.2 | | |
| APF | 4.8** | 4.0** | 3.8** | 2.6** | 1.6** | 1.4** | 1.0** | 0.8** | |
| AXF | 6.2** | 5.4** | 5.2** | 4.0** | 2.8** | 2.8** | 2.2** | 2.2** | 1.4** |

[a] Positive number indicates increase in spring diurnal surface temperature variation mean for the agricultural cover/soil type compared to that of the left-column agricultural cover/soil type. The agricultural cover/soil types are denoted as follows: AXU = mixed agriculture on upland loamy sand, AXS = mixed agriculture on deep sand, AXR = mixed agriculture on sandy rockland, ACU = citrus orchard on upland loamy sand, ACS = citrus orchard on deep sand, ACF = citrus orchard on flatwoods sand, ARM = row-crops on muck, ASM = pasture/sod on muck, APF = pasture/range on flatwoods sand, and AXF = mixed agriculture on flatwoods sand. These cover/soil types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

agricultural type, while flatwoods sand appears to lower the DSTV of a given agricultural type.

Agriculture type impacts on soil type temperatures were compared. Among the deep sand combinations, mixed agriculture had higher DSTV (by 2.6 C) than did citrus orchard. Among the upland loamy sand combinations, mixed agriculture had higher DSTV (by 2.2 C) than did citrus orchard. Among the flatwoods sand combinations, citrus orchard had higher DSTV than did either mixed agriculture or pasture/range. Among the muck combinations, there was no significant difference in DSTV between row-crops and pasture/sod. In zone N in spring, differences in AST among certain agricultural types were substantial on mineral soils, but not on muck.

<u>Zone S.</u> Within zone S, there were five agriculture types on up to six different soil types. Listed in order of decreasing mean DSTV (C), these combinations included mixed agriculture on muck (20.2), row-crops on flatwoods sand (15.8), mixed agriculture on sandy rockland (17.6), citrus orchard on deep sand (17.2), pasture/sod on muck (15.0), mixed agriculture on flatwoods sand (16.8), mixed agriculture on marly rockland (16.0), pasture/range on sandy rockland (15.6), citrus orchard on flatwoods sand (15.2), pasture/range on flatwoods sand (15.2), row-crops on marly rockland (14.6), and row-crops on coastal sand (15.8). Differences in mean DSTV among zone S agricultural/soil type combinations are given in Table 54. Among these agricultural land cover types, the

Table 54. Spring diurnal surface temperature variation differences among agricultural land-cover types in south zone.

| Agric. cover/ soil type | Difference in DSTV (C) mean for agricultural cover/soil type[a] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | AXM | AXR | ACS | AXF | AXL | ARF | APR | APF | ACF | ASM | ARL |
| AXR | 2.8** | | | | | | | | | | |
| ACS | 3.0** | 0.4* | | | | | | | | | |
| AXF | 3.4** | 0.8** | 0.4** | | | | | | | | |
| AXL | 4.2** | 1.6** | 1.2** | 0.8** | | | | | | | |
| ARF | 4.4** | 1.8** | 1.4** | 1.0** | 0.2 | | | | | | |
| APR | 4.6** | 2.0** | 1.6** | 1.2** | 0.4 | 0.2 | | | | | |
| APF | 5.0** | 2.4** | 2.0** | 1.6** | 0.8** | 0.6** | 0.4** | | | | |
| ACF | 5.2** | 2.4** | 2.0** | 1.8** | 1.0** | 0.8** | 0.6** | 0.2 | | | |
| ASM | 5.2** | 2.4** | 2.2** | 1.8** | 1.0** | 0.8* | 0.6* | 0.2 | 0.0 | | |
| ARL | 5.6** | 2.8** | 2.4** | 2.1** | 1.4** | 1.2** | 1.0** | 0.6** | 0.4* | 0.4 | |
| ARC | 10.6** | 7.8** | 7.4** | 7.0** | 6.4** | 6.0** | 5.8** | 5.4** | 5.4** | 5.4** | 5.0** |

[a] Positive number indicates increase in spring diurnal surface temperature variation mean for the agricultural cover/soil type compared to that of the left-column agricultural cover/soil type. The agricultural cover/soil types are denoted as follows: AXM = mixed agriculture on muck, AXR = mixed agriculture on sandy rockland, ACS = citrus orchard on deep sand, AXF = mixed agriculture on flatwoods sand, AXL = mixed agriculture on marly rockland, ARF = row-crops on flatwoods sand, APR = pasture/range on sandy rockland, APF

Table 54--Continued.

= pasture/range on flatwoods sand, ACF = citrus orchard on flatwoods sand, ASM = pasture/sod on muck, ARL = row-crops on marly rockland, and ARC = row-crops on coastal sand. These cover/soil types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

highest difference in DSTV (10.6 C) was between mixed agriculture on muck and row-crops on coastal sand.

Soil type impacts on agricultural type temperatures were compared. Among the mixed agriculture combinations, the highest difference in DSTV (4.2 C) was between that on muck and that on marly rockland. Among the row-crop combinations, the highest difference in mean DSTV (6.0 C) was between that on flatwoods sand and that on coastal sand. Differences between other row-crop combinations were both significant and substantial. Among the pasture combinations, the differences between pasture/sod on muck and pasture/range on flatwoods sand and on sandy rockland were significant, but not substantial. Among the citrus orchard combinations, that on deep sand had higher DSTV (by 2.0 C) than did that on flatwoods sand. This was expected, due to the excessively-drained character of the deep sand. In zone S in spring, the DSTV of most agricultural types (other than pasture) appears to be increased the most by muck, followed respectively by sandy rockland, deep sand, flatwoods sand, and marly rockland.

Agriculture type impacts on soil type temperatures were compared. Among the muck combinations, mixed agriculture had higher DSTV (by 5.2 C) than did pasture/sod. This was expected, since mixed agriculture includes more exposed soil, and is maintained under a lower water-table condition than is pasture. Among the sandy rockland combinations, mixed agriculture had higher DSTV (by 2.0 C) than did pasture/range. This was expected, since mixed agriculture includes more

exposed soil, and is maintained under a lower water-table condition than is pasture. Among the marly rockland combinations, mixed agriculture had higher DSTV (by 1.4 C) than did row-crops. This was expected, since mixed agriculture is maintained under a lower water-table condition than are row-crops. Among the flatwoods sand combinations, mixed agriculture had higher DSTV (by 1.0 C) than did row-crops, which was expected, since mixed agriculture is maintained under a lower water-table condition than row-crops. There were no substantial differences between row-crops, pasture/range, and citrus orchard. In zone S in spring, mixed agriculture appeared to increase DSTV more than did other agricultural types on most soil types.

Spring Diurnal Urban/Industrial Land-Cover Thermal Patterns

Zone P. Within zone P, there were two types of urban/industrial land cover, distributed on four soil types. Listed in order of decreasing mean DSTV (C), these included urban center on deep sand (17.8), urban center on upland loamy sand (16.0), urban center on flatwoods sand (12.4), urban center on coastal sand (10.8), and suburb on coastal sand (10.4). Differences in mean DSTV among zone P urban/industrial cover/soil type combinations are given in Table 55; most were significant, and many were substantial. The highest difference in DSTV (7.4 C) was between urban center on deep sand and suburb on coastal sand. Among the urban center types, the highest difference (7.0 C) was between that on deep

Table 55. Spring diurnal surface temperature variation differences among urban/industrial land-cover types in panhandle zone.

| Urban/indus. cover/soil type | Difference in DSTV (C) mean for urban/industrial cover/soil type[a] | | | |
| --- | --- | --- | --- | --- |
| | UCS | UCU | UCF | UCC |
| UCU | 1.8** | | | |
| UCF | 5.4** | 3.8** | | |
| UCC | 7.0** | 5.2** | 1.6** | |
| USC | 7.4** | 5.8** | 2.0** | 0.6 |

[a] Positive number indicates increase in spring diurnal surface temperature variation mean for the urban/industrial cover/soil type compared to that of the left-column urban/industrial cover/soil type. The urban/industrial cover/soil types are UCS = urban center on deep sand, UCU = urban center on upland loamy sand, UCF = urban center on flatwoods sand, UCC = urban center on coastal sand, and USC = suburb on coastal sand. These cover/soil types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

sand and that on coastal sand. The difference between urban center on coastal sand and suburb on coastal sand was significant, but not substantial.

<u>Zone N.</u> Within zone N, there were six urban/industrial cover types present on five different soil types. Listed in order of decreasing mean DSTV (C), the combinations included urban center on sandy rockland (18.4), suburb on deep sand (17.6), platted suburb on flatwoods sand (17.0), urban center on upland loamy sand (16.8), titanium mine on deep sand (16.8), urban center on deep sand (15.6), suburb on upland loamy sand (15.4), suburb on flatwoods sand (14.4), urban center on flatwoods sand (13.8), phosphate mine on flatwoods sand (13.4), suburb on sandy rockland (11.6), golf-course suburb on flatwoods sand (11.0), and suburb on coastal sand (10.2). Differences in mean DSTV among zone N urban/ industrial cover/soil type combinations are given in Table 56. Among these land cover types, the highest DSTV difference (8.2 C) was between urban center on sandy rockland and suburb on coastal sand.

Soil type impacts on urban/industrial type temperatures were compared. Among the suburb combinations, the highest difference in mean DSTV (7.4 C) was between suburb on deep sand and that on coastal sand. Among the urban center combinations, the highest difference in DSTV (4.6 C) was between that on sandy rockland and that on flatwoods sand. The differences between other urban center combinations were significant and substantial. Among the mine combinations,

Table 56. Spring diurnal surface temperature variation differences among urban/industrial land-cover types in north zone.

| Urban/ indus. cover/ soil type | Difference in DSTV (C) mean for urban/industrial cover/soil type[a] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | UCR | USS | UPF | UCU | UMS | UCS | USU | USF | UCF | UMF | USR | UGF |
| USS | 0.8** | | | | | | | | | | | |
| UPF | 1.2** | 0.4** | | | | | | | | | | |
| UCU | 1.6** | 0.6** | 0.2* | | | | | | | | | |
| UMS | 1.6** | 0.8** | 0.4 | 0.0 | | | | | | | | |
| UCS | 2.8** | 2.0** | 1.6** | 1.2** | 1.2** | | | | | | | |
| USU | 3.0** | 2.2** | 1.8** | 1.4** | 1.4** | 0.2** | | | | | | |
| USF | 4.0** | 3.2** | 2.8** | 2.6** | 2.4** | 1.2** | 1.0** | | | | | |
| UCF | 4.6** | 3.6** | 3.2** | 3.0** | 3.0** | 1.8** | 1.6** | 0.4** | | | | |
| UMF | 5.0** | 4.2** | 3.8** | 3.6** | 3.4** | 2.2** | 2.0** | 1.0** | 0.6** | | | |
| USR | 6.8** | 5.8** | 5.4** | 5.2** | 5.2** | 4.0** | 3.8** | 2.8** | 2.2** | 1.6** | | |
| UGF | 7.4** | 6.4** | 6.0** | 5.8** | 5.8** | 4.6** | 4.4** | 3.4** | 2.8** | 2.4** | 0.6* | |
| USC | 8.2** | 7.4** | 7.0** | 6.6** | 6.6** | 5.4** | 5.2** | 4.2** | 3.6** | 3.2** | 1.4** | 0.8** |

[a] Positive number indicates increase in spring diurnal surface temperature variation mean for the urban/industrial cover/soil type compared to that of the left-column urban/industrial cover/soil type. The urban/industrial cover/soil types are denoted as follows: UCR =

Table 56--Continued.

urban center on sandy rockland, USS = suburb on deep sand, UPF = platted suburb on flatwoods sand, UCU = urban center on upland loamy sand, UMS = titanium mine on deep sand, UCS = urban center on deep sand, USU = suburb on upland loamy sand, USF = suburb on flatwoods sand, UCF = urban center on flatwoods sand, UMF = phosphate mine on flatwoods sand, USR = suburb on sandy rockland, UGF = golf-course suburb on flatwoods sand, and USC = suburb on coastal sand. These cover/soil types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

titanium mine on deep sand had higher DSTV (by 3.4 C) than did phosphate mine on flatwoods sand, which can be attributed to the presence of settling ponds within the phosphate mine. In zone N in spring, soil type appears to have a substantial effect on the DSTV for all urban/industrial types.

Urban/industrial type impacts on soil type temperatures were compared. Among the deep sand combinations, suburb had higher DSTV than did urban center (by 2.0 C). Among the rockland combinations, urban center had higher DSTV (by 6.8 C) than did suburb. Among the upland loamy sand combinations, urban center had higher DSTV (by 1.4 C) than did suburb. Among the flatwoods sand combinations, the highest difference in DSTV (6.0 C) was between phosphate mine and golf-course suburb. The difference between urban center and suburb was sighnificant, but not substantial. Golf-course suburb had lower DSTV (by 2.4 C or more) than did other urban/industrial types, which can be attributed to the moderation of the nighttime component of DSTV through nighttime irrigation. There was only one cover type present on coastal sand (suburb). In zone N in spring, most urban/industrial cover types had a substantial effect on the DSTV for a given soil type.

Zone S. Within zone S, there were five urban/industrial cover types present on up to five different soil types. Listed in order of decreasing DSTV (C) means, the combinations included golf-course suburb on flatwoods sand (19.6), urban center on sandy rockland (19.6), suburb on flatwoods sand

(17.2), golf-course suburb on sandy rockland (16.4), urban center on muck (16.0), urban center on flatwoods sand (16.0), suburb on marly rockland (15.2), Indian reservation on flatwoods sand (14.8), finger-canal suburb on flatwoods sand (13.6), and finger-canal suburb on coastal sand (8.6). Differences in mean DSTV among zone S urban/industrial cover/soil type combinations are given in Table 57; most were significant, and many were substantial. Among these land cover types, the highest DSTV difference (11.2 C) was between golf-course suburb on flatwoods sand and finger-canal suburb on coastal sand.

Soil type impacts on urban/industrial type temperatures were compared. Among the suburb combinations, the highest difference in DSTV (11.2 C) was between golf-course suburb on flatwoods sand and finger-canal suburb on coastal sand. Among the normal suburbs, that on flatwoods sand had higher DSTV (by 2.0 C) than did that on marly rockland. Among the finger-canal suburbs, that on flatwoods sand had higher DSTV (by 5.0 C) than did that on coastal sand. Among the golf-course suburbs, that on flatwoods sand had higher DSTV (by 3.2 C) than did that on sandy rockland. Among the urban center combinations, that on sandy rockland had higher DSTV (by 3.6 C) than did that on either flatwoods sand or muck. In zone S in spring, soil type appears to have a substantial effect on the DSTV for urban/industrial land-cover types.

Urban/industrial type impacts on soil type temperatures were compared. Among the flatwoods sand combinations, the

Table 57. Spring diurnal surface temperature variation differences among urban/industrial land-cover types in south zone.

| Urban/ indus. cover/ soil type | Difference in DSTV (C) mean for urban/industrial cover/soil type[a] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | UGF | UCR | USF | UGR | UCM | UCF | USL | URF | UFF |
| UCR | 0.2 | | | | | | | | |
| USF | 2.6** | 2.4** | | | | | | | |
| UGR | 3.2** | 3.0** | 0.6* | | | | | | |
| UCM | 3.8** | 3.6** | 1.2** | 0.6 | | | | | |
| UCF | 3.8** | 3.6** | 1.2** | 0.6 | 0.0 | | | | |
| USL | 4.6** | 4.4** | 2.0** | 1.4** | 0.8** | 0.8** | | | |
| URF | 5.0** | 4.8** | 2.4** | 1.8** | 1.2** | 1.2** | 0.4* | | |
| UFF | 6.2** | 6.0** | 3.6** | 3.0** | 2.4** | 2.4** | 1.6** | 1.2** | |
| UFC | 11.2** | 11.0** | 8.6** | 8.0** | 7.4** | 7.4** | 6.6** | 6.2** | 5.0** |

[a] Positive number indicates increase in spring diurnal surface temperature variation mean for the urban/industrial cover/soil type compared to that of the left-column urban/industrial cover/soil type. The urban/industrial cover/soil types are denoted as follows: UGF = golf-course suburb on flatwoods sand, UCR = urban center on sandy rockland, USF = suburb on flatwoods sand, UGR = golf-course suburb on sandy rockland, UCM = urban center on muck, UCF = urban center on flatwoods sand, USL = suburb on marly rockland, URF = Indian reservation on flatwoods sand, UFF = finger-canal suburb on flatwoods sand, and UFC = finger-canal suburb on coastal sand. These cover/soil types are further described in the text.

Table 57--Continued.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

highest difference in DSTV (6.2 C) was between golf-course suburb and finger-canal suburb. Differences in AST among all of the flatwoods sand combinations were both significant and substantial. In particular, golf-course suburb had higher DSTV (by 2.6 C) than did suburb, and suburb had higher DSTV (by 3.6 C) than did finger-canal suburb. This can be attributed to the effects of golf-course windbreak vegetation, and to the moderating effects of the fractional water surface in finger canals. Among the sandy rockland combinations, urban center had higher DSTV (by 3.0 C) than did golf-course suburb. In zone S in spring, urban/industrial cover type appears to have a substantial effect on the DSTV for a given soil type.

### Spring Diurnal Change Analyses--Natural to Agricultural Land-Cover

Zone P. Differences in mean DSTV between zone P agricultural/soil type combinations and their original cover types are given in Table 58. Mixed agriculture on deep sand had a higher DSTV (by 2.0 C) than did the mixed scrub which was its original land-cover. Other differences between agricultural types and their original land-cover were significant, but not substantial. Within zone P in spring, conversion from natural to mixed agriculture use appears to increase DSTV on deep sand, while conversion from natural to agricultural use on other soil types appears to have no substantial effect.

Table 58. Spring diurnal surface temperature variation change from natural to agricultural in panhandle zone.

| Soil type and natural cover | Difference in DSTV (C) mean for agricultural cover type[a] | |
|---|---|---|
| | Pasture/range | Mixed |
| Sand, deep (mixed scrub) | --- | 2.0** |
| Sand, loamy (upland mixed forest) | --- | 0.4** |
| Sand, flatwoods (flatwoods forest) | -0.6** | --- |

[a] Positive number indicates increase in spring diurnal surface temperature variation mean for agricultural cover type compared to that of the natural cover for the soil type.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Zone N. Differences in mean DSTV between zone N agricultural/soil type combinations and their original cover types are given in Table 59. Among the mixed agriculture combinations, increased DSVT compared to that of the original land-cover types was observed for all soil types except flatwoods sand. In zone N in spring, conversion from natural to mixed agriculture use appears to increase DSTV on upland loamy sand, deep sand, and sandy rockland, and to decrease DSTV on flatwoods sand. Row-crops on muck had higher DSTV (by 3.6 C) than did the marsh which was its original land cover. In zone N in spring, conversion from natural to row-crops use appears to increase DSTV on muck. Among the pasture combinations, pasture/sod on muck had higher DSTV (by 3.4 C) than did marsh, while pasture/range on flatwoods sand had lower DSTV (by 1.0 C) than did flatwoods forest. In zone N in spring, conversion from natural to pasture use appears to increase DSTV on muck, and to decrease DSTV on flatwoods sand. Among the citrus orchard combinations, that on upland loamy sand had higher DSTV (by 2.2 C) than did the upland forest, while the DSTV on other soil types was not substantially changed from that of the original cover. In zone N in spring, conversion from natural to citrus orchard use appears to increase DSTV on upland loamy sand, but not on other soil.

Zone S. Differences in mean DSTV between zone S agricultural/soil type combinations and their original cover types are given in Table 60. Among the mixed agriculture combinations, increased DSTV was found for all soil types

Table 59. Spring diurnal surface temperature variation change from natural to agricultural in north zone.

| Soil type and natural cover | Difference in DSTV (C) mean for agricultural cover type[a] | | | | |
|---|---|---|---|---|---|
| | Row-crops | Pasture/range | Pasture/sod | Citrus orchard | Mixed |
| Sand, deep (mixed scrub) | --- | --- | --- | --- | 1.6** |
| Sand, deep (evergreen scrub) | --- | --- | --- | -0.4** | --- |
| Sand, loamy (upland mixed forest) | --- | --- | --- | 2.2** | 4.4** |
| Sand, flatwoods (flatwoods forest) | --- | -1.0** | --- | 0.4** | -2.4** |
| Rockland, sandy (calcareous hammock[b]) | --- | --- | --- | --- | 3.4** |
| Organic, muck (marsh) | 3.6** | --- | 3.4** | --- | --- |

[a] Positive number indicates increase in spring diurnal surface temperature variation mean for agricultural cover type compared to that of the natural cover for the soil type.

[b] Represented by upland mixed forest.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Table 60. Spring diurnal surface temperature variation change from natural to agricultural in south zone.

| Soil type and natural cover | Difference in DSTV (C) mean for agricultural cover type[a] | | | | |
|---|---|---|---|---|---|
| | Row-crops | Pasture/ range | Pasture/ sod | Citrus orchard | Mixed |
| Sand, deep (evergreen scrub) | --- | --- | --- | -1.0** | --- |
| Sand, flatwoods (flatwoods forest) | 3.4** | 2.8** | --- | 2.6** | 4.4** |
| Sand, coastal (coastal hammock) | 1.4** | --- | --- | --- | --- |
| Rockland, sandy (rockland hammock) | --- | 1.2** | --- | --- | 3.2** |
| Rockland, marly (rockland hammock) | 0.2 | --- | --- | --- | 1.6** |
| Organic, muck (marsh) | --- | --- | 6.6** | --- | 11.8** |

[a] Positive number indicates increase in spring diurnal surface temperature variation mean for agricultural cover type compared to that of the natural cover for the soil type.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

compared to that of the original land-cover. Among the row-crops combinations, that on flatwoods sand and coastal sand had higher DSTV than did the original cover, while that on marly rockland did not. Among the pasture combinations, pasture/range on sandy rockland and on flatwoods sand, and pasture/sod on muck, all had higher DSTV than did their original cover. Among the citrus orchard combinations, that on flatwoods sand had higher DSTV than did the original cover, while that on deep sand had lower DSTV than did the original cover. This can be attributed to the effects of irrigation on citrus orchard DSTV for the case of deep sand. In zone S in spring, conversion from natural to mixed agriculture use appears to increase DSTV on all soil types, especially on muck. Conversion from natural to row-crops use appears to increase DSTV on flatwoods sand and coastal sand, but not on marly rockland. Conversion from natural to pasture use appears to increase DSTV on all soil types, especially on muck. Conversion from natural to citrus orchard use appears to increase DSTV on flatwoods sand, and to decrease DSTV on deep sand.

### Spring Diurnal Change Analyses--Natural to Urban/Industrial Land-Cover

Zone P. Differences in mean DSTV between zone P urban/ industrial cover/soil type combinations and their original cover types are given in Table 61. An increase in DSTV was observed for both suburb and urban center on coastal sand,

Table 61. Spring diurnal surface temperature variation change from natural to urban/industrial in panhandle zone.

| | Difference in DSTV (C) mean for urban/industrial cover type[a] | |
|---|---|---|
| Soil type and natural cover | Suburb | Urban center |
| Sand, deep (mixed scrub) | --- | 1.6** |
| Sand, loamy (upland mixed forest) | --- | 0.2 |
| Sand, flatwoods (flatwoods forest) | --- | -2.4** |
| Sand, coastal (coastal hammock) | 3.2** | 3.8** |

[a] Positive number indicates increase in spring diurnal surface temperature variation mean for urban/industrial cover type compared to that of the natural cover for the soil type.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

compared to that of the coastal hammock which was their original cover. Urban center had higher DSTV than did the original cover for deep sand and coastal sand, but had lower DSTV than did the original cover for flatwoods sand. Within zone P in spring, conversion from natural to urban/industrial use appears to increase DSTV on deep sand and coastal sand, and to decrease DSTV on flatwoods sand.

Zone N. Differences in mean DSTV between zone N urban/industrial cover/soil type combinations and their original cover types are given in Table 62. Among the suburb combinations, that on deep sand and on sandy rockland had higher DSTV than did the original cover, while that on flatwoods sand had lower DSTV than did the original cover type. Among the urban center combinations, that on upland loamy sand and on sandy rockland had higher DSTV than did the original cover, while that on deep sand and on flatwoods sand had lower DSTV than did the original cover. Among the mine combinations, phosphate mine on flatwoods sand had lower DSTV (by 2.4 C) than did flatwoods forest, while titanium mine did not have DSTV substantially different from mixed scrub. All of the urban industrial land-cover types on flatwoods sand had lower DSTV than did the original flatwoods forest, except for platted suburb. This can be attributed to the previously described characteristics of platted suburb. In zone N in spring, conversion of natural cover to urban/industrial use appears to have variable, but substantial, effects on DSTV for most soil types.

Table 62. Spring diurnal surface temperature variation change from natural to urban/industrial in north zone.

| Soil type and natural cover | Difference in DSTV (C) mean for urban/industrial cover type[a] | | | | | |
|---|---|---|---|---|---|---|
| | Suburb | Platted suburb | Golf-course suburb | Urban center | Phos. mine | Titan. mine |
| Sand, deep (mixed scrub) | --- | --- | --- | --- | --- | -0.2 |
| Sand, deep (evergreen scrub) | 1.0** | --- | --- | -1.0** | --- | --- |
| Sand, loamy (upland mixed forest) | 0.4* | --- | --- | 1.8** | --- | --- |
| Sand, flatwoods (flatwoods forest) | -1.4** | 1.4** | -4.6** | -1.8** | -2.4** | --- |
| Sand, coastal (coastal hammock) | 0.6* | --- | --- | --- | --- | --- |
| Rockland, sandy (rockland hammock) | 1.0** | --- | --- | --- | --- | --- |
| Rockland, sandy (calcareous hammock[b]) | --- | --- | --- | 3.4** | --- | --- |

Table 62--Continued.

[a] Positive number indicates increase in spring diurnal surface temperature variation mean for urban/industrial cover type compared to that of the natural cover for the soil type.

[b] Represented by upland mixed forest.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Zone S. Differences in mean DSTV between zone S urban/industrial soil type combinations and their original cover types are given in Table 63. All of the suburb combinations on flatwoods sand--suburb, finger-canal suburb, golf-course suburb, and Indian reservation on flatwoods sand, had higher DSTV than did flatwoods forest. The result for finger-canal suburb on flatwoods sand indicates that the fractional water surface included in it does not completely mask its kilometer-scale thermal pattern. The difference in DSTV between suburb on marly rockland and rockland hammock was significant, but not substantial. Golf-course suburb on sandy rockland and on flatwoods sand had higher DSTV than did the original land-cover. There was no significant difference between finger-canal suburb on coastal sand and its original cover. All of the urban center combinations had higher DSTV than did their original cover. In zone S in spring, conversion from natural to suburb, finger-canal suburb, golf-course suburb, Indian reservation, or urban center use appeared to increase DSTV for most soil types (except coastal sand and marly rockland).

Spring Diurnal Change Analyses--Agricultural to Urban/ Industrial Land-Cover.

Zone P. Differences in mean DSTV between zone P urban/industrial cover/soil type combinations and their agricultural counterparts are given in Table 64. Urban center on flatwoods sand had lower DSTV (by 1.8 C) than did pasture/

Table 63. Spring diurnal surface temperature variation change from natural to urban/industrial in south zone.

| Soil type and natural cover | Difference in DSTV (C) mean for urban/industrial cover type[a] | | | | |
|---|---|---|---|---|---|
| | Suburb | Finger-canal suburb | Golf-course suburb | Indian reserv. | Urban center |
| Sand, flatwoods (flatwoods forest) | 4.6** | 1.0** | 7.2** | 2.2** | 3.4** |
| Sand, coastal (coastal hammock) | --- | 0.2 | --- | --- | --- |
| Rockland, sandy (rockland hammock) | --- | --- | 2.0** | --- | 5.2** |
| Rockland, marly (rockland hammock) | 0.6** | --- | --- | --- | --- |
| Organic, muck (marsh) | --- | --- | --- | --- | 7.6** |

[a] Positive number indicates increase in spring diurnal surface temperature variation mean for urban/industrial cover type compared to that of the natural cover for the soil type.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Table 64. Spring diurnal surface temperature variation change from agricultural to urban/industrial in panhandle zone.

| Soil type and agric. cover | Difference in DSTV (C) mean for urban/industrial cover type[a] |
| --- | --- |
| | Urban center |
| Sand, deep (mixed agric.) | -0.4 |
| Sand, loamy (mixed agric.) | -0.2 |
| Sand, flatwoods (pasture/ range) | -1.8** |

[a] Positive number indicates increase in spring diurnal surface temperature variation mean for urban/industrial cover type compared to that of the agricultural cover for the soil type.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

range on flatwoods sand. There no significant differences in mean DSTV between urban center and mixed agriculture on either deep sand or upland loamy sand. Within zone P in spring, conversion from pasture/range to urban center use appears to decrease DSTV on flatwoods sand, but not for mixed agriculture on other soils.

<u>Zone N.</u> Differences in mean DSTV between zone N urban/industrial cover/soil type combinations and their agricultural counterparts are given in Table 65. Normal suburb had lower DSTV than its agricultural counterparts, except for the cases of citrus orchard on deep sand and of mixed agriculture on flatwoods sand. Platted suburb had higher DSTV than all agricultural types on flatwoods sand, which can be attributed to its cleared land surface and lack of irrigation. Golf-course suburb had lower DSTV than all agricultural types on flatwoods sand. Urban center had either similar or lower DSTV than did agricultural cover on all soil types. Phosphate mine had lower DSTV than did either pasture/range or citrus orchard, but was not significantly different from mixed agriculture on flatwoods sand. The latter observation can be attributed to the similarities of phosphate mine and mixed agriculture on flatwoods sand--both have cleared land and ponds. Titanium mine had lower DSTV than did mixed agriculture, but was not substantially different from citrus orchard on deep sand. The latter observation can be attributed to the irrigation of citrus orchard on deep sand, and the presence of ponds within

Table 65. Spring diurnal surface temperature variation change from agricultural to urban/industrial in north zone.

| Soil type and agric. cover | Difference in DSTV (C) mean for urban/industrial cover type[a] | | | | | |
|---|---|---|---|---|---|---|
| | Suburb | Platted suburb | Golf-course suburb | Urban center | Phos. mine | Titan. mine |
| Sand, deep (citrus orchard) | 1.4** | --- | --- | -0.6** | --- | 0.6** |
| Sand, deep (mixed agric.) | -1.2** | --- | --- | -3.0** | --- | -2.0** |
| Sand, loamy (citrus orchard) | -1.8** | --- | --- | -0.4** | --- | --- |
| Sand, loamy (mixed agric.) | -4.0** | --- | --- | -2.6** | --- | --- |
| Sand, flatwoods (pasture/ range) | -0.4** | 2.4** | -3.6** | -0.8** | -1.4** | --- |
| Sand, flatwoods (citrus orchard) | -1.6** | 1.0** | -5.0** | -2.2** | -2.6** | --- |
| Sand, flatwoods (mixed agric.) | 1.0** | 3.8** | -2.2** | 0.6** | 0.0 | --- |
| Rockland, sandy (mixed agric.) | --- | --- | --- | 0.0 | --- | --- |

Table 65--Continued.

[a] Positive number indicates increase in spring diurnal surface temperature variation mean for urban/industrial cover type compared to that of the agricultural cover for the soil type.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

titanium mine land. In zone N in spring, conversion of most agricultural cover types to urban/industrial cover appears to to decrease DSTV, except for conversion from agricultural cover to platted suburb on flatwoods sand--which appears to increase DSTV.

Zone S. Differences in mean DSTV between zone S urban/industrial cover/soil type combinations and their agricultural counterparts are given in Table 66. Normal suburb had higher DSTV than did its agricultural counterparts on most soils, except for the case of mixed agriculture on marly rockland. Finger-canal suburb had lower DSTV than did its agricultural counterparts, except for the case of row-crops on coastal sand. Golf-course suburb had similar or higher DSTV than did its agricultural counterparts, except for the case of mixed agriculture on sandy rockland. Indian reservation had similar or lower DSTV than did agricultural types on flatwoods sand. Urban center had higher DSTV than did agricultural types on sandy rockland, and had similar or lower DSTV than agricultural types on other soils--especially on muck. In zone S in spring, conversion from agricultural cover to suburb or golf-course suburb on most soil types appears to increase DSTV, while conversion from agricultural cover to finger-canal suburb or Indian reservation on flatwoods sand appears to decrease DSTV, and conversion from agricultural cover to urban center has variable effects on DSTV depending on soil type.

Table 66. Spring diurnal surface temperature variation change from agricultural to urban/industrial in south zone.

| Soil type | Difference in DSTV (C) mean for urban/industrial cover type[a] | | | | |
|---|---|---|---|---|---|
| | Suburb | Finger-canal suburb | Golf-course suburb | Indian reserv. | Urban center |
| Sand, flatwoods (row-crops) | 1.4** | -2.4** | 3.8** | -1.2** | 0.0 |
| Sand, flatwoods (pasture/range) | 2.0** | -1.8** | 4.4** | -0.6** | 0.6** |
| Sand, flatwoods (citrus orchard) | 2.0** | -1.6** | 4.6** | -0.4** | 0.8** |
| Sand, flatwoods (mixed agric.) | 0.4** | -3.4** | 2.8** | -2.2** | -1.0** |
| Sand, coastal (row-crops) | --- | 3.2** | --- | --- | --- |
| Rockland, sandy (pasture/range) | --- | --- | 0.8** | --- | 4.0** |
| Rockland, sandy (mixed agric.) | --- | --- | -1.0** | --- | 2.0** |
| Rockland, marly (row-crops) | 0.4 | --- | --- | --- | --- |
| Rockland, marly (mixed agric.) | -1.0** | --- | --- | --- | --- |
| Organic, muck (pasture/sod) | --- | --- | --- | --- | 0.8** |
| Organic, muck (mixed agric.) | --- | --- | --- | --- | -4.4** |

[a] Positive number indicates increase in spring diurnal surface temperature variation mean for urban/industrial cover type compared to that of the agricultural cover for the soil type.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Spring Diurnal Comparison of Agricultural to Natural Extreme Islands

Zone P. Differences in mean DSTV between agricultural cover types and the highest-DSTV natural feature of zone P (mixed scrub) are given in Table 67. Mixed agriculture on deep sand had higher DSTV (by 2.0 C) than did the mixed scrub. The difference between mixed agriculture on upland loamy sand and mixed scrub was significant, but not substantial. Pasture/range on flatwoods sand had lower DSTV than did the mixed scrub. Within zone P in spring, mixed agriculture on upland loamy sand had DSTV matching that of the highest-DSTV natural feature, but mixed agriculture on deep sand had DSTV substantially exceeding it.

Zone N. Differences in mean DSTV between agricultural cover types and the highest-DSTV natural feature of zone N (mixed scrub) are given in Table 67. Mixed agriculture on deep sand, upland loamy sand, and sandy rockland had higher DSTV (by up to 2.4 C) than did mixed scrub. The difference between citrus orchard on upland loamy sand and mixed scrub was significant, but not substantial. Other agricultural combinations had lower DSTV than did mixed scrub. In zone N in spring, citrus orchard on upland loamy sand had DSTV matching that of the highest-DSTV natural feature, but mixed agriculture on deep sand, upland loamy sand, and sandy rockland had DSTV substantially exceeding it.

Zone S. Differences in mean DSTV between agricultural cover types and the highest-DSTV natural feature of zone S

Table 67. Spring diurnal surface temperature variation of agricultural land-cover types vs highest-DSTV natural land-cover.

| Soil type | Difference in DSTV (C) mean for agricultural cover type[a] Row-crops | Pasture/ range | Pasture/ sod | Citrus orchard | Mixed |
|---|---|---|---|---|---|
| Zone P | | | | | |
| Sand, deep | --- | --- | --- | --- | 2.0** |
| Sand, loamy | --- | --- | --- | --- | 0.0 |
| Sand, flatwoods | --- | -2.0** | --- | --- | --- |
| Zone N | | | | | |
| Sand, deep | --- | --- | --- | -0.8** | 1.6** |
| Sand, loamy | --- | --- | --- | 0.2 | 2.4** |
| Sand, flatwoods | --- | -2.4** | --- | -1.0** | -3.8** |
| Rockland, sandy | --- | --- | --- | --- | 1.4** |
| Organic, muck | -1.4** | --- | -1.6** | --- | --- |
| Zone S | | | | | |
| Sand, deep | --- | --- | --- | -1.0** | --- |
| Sand, flatwoods | -2.4** | -3.0** | --- | -3.2** | -1.4** |
| Sand, coastal | -8.6** | --- | --- | --- | --- |
| Rockland, sandy | --- | -2.6** | --- | --- | -0.8** |
| Rockland, marly | -3.6** | --- | --- | --- | -2.2** |
| Organic, muck | --- | --- | -3.2** | --- | 2.0** |

[a] Positive number indicates increase in spring diurnal surface temperature variation mean for agricultural cover type compared to that of highest-DSTV natural cover type (mixed scrub in zones P and N, evergreen scrub in zone S).

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

(evergreen scrub) are given in Table 67. Mixed agriculture on muck had higher DSTV than did evergreen scrub. The difference in DSTV between mixed agriculture on sandy rockland and evergreen scrub was significant, but not substantial. Other agricultural combinations had lower DSTV than did evergreen scrub. In zone S in spring, mixed agriculture on sandy rockland had DSTV matching that of the highest-DSTV natural feature, while mixed agriculture on muck had DSTV substantially exceeding it.

## Spring Diurnal Comparison of Urban/Industrial to Natural Extreme Islands

Zone P. Differences in mean DSTV between urban/industrial cover types and the highest-DSTV natural feature of zone P (mixed scrub) are given in Table 68. Urban center on deep sand had higher DSTV than did mixed scrub. The difference between urban center on upland loamy sand and mixed scrub was significant, but not substantial. Other agricultural combinations had lower DSTV than did mixed scrub. Within zone P in spring, urban center on upland loamy sand had DSTV matching that of the highest-DSTV natural feature, while urban center on deep sand had DSTV substantially exceeding it.

Zone N. Differences in mean DSTV between urban/industrial cover types and the highest-DSTV natural feature of zone N (mixed scrub) are given in Table 68. Urban center on sandy rockland had higher DSTV than did mixed scrub. Suburb on deep sand, platted suburb on flatwoods sand, urban center

Table 68. Spring diurnal surface temperature variation of urban/industrial land-cover types vs highest-DSTV natural land-cover.

| Soil type | Difference in DSTV (C) mean for urban/industrial cover type[a] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Suburb | Platted suburb | Finger-canal suburb | Golf-course suburb | Indian reserv. | Urban center | Phos. mine | Tita. mine |
| Zone P | | | | | | | | |
| Sand, deep | --- | --- | --- | --- | --- | 1.6** | --- | --- |
| Sand, loamy | --- | --- | --- | --- | --- | 0.0 | --- | --- |
| Sand, flatwoods | --- | --- | --- | --- | --- | -3.8** | --- | --- |
| Sand, coastal | -5.8** | --- | --- | --- | --- | -5.2** | --- | --- |
| Zone N | | | | | | | | |
| Sand, deep | 0.6** | --- | --- | --- | --- | -1.4** | --- | -0.2 |
| Sand, loamy | -1.6** | --- | --- | --- | --- | -0.2 | --- | --- |
| Sand, flatwoods | -2.6** | 0.0 | --- | -6.0** | --- | -3.2** | -3.6** | --- |
| Sand, coastal | -6.8** | --- | --- | --- | --- | --- | --- | --- |
| Rockland, sandy | -5.4** | --- | --- | --- | --- | 1.4** | --- | --- |

Table 68--Continued.

| Soil type | Difference in DSTV (C) mean for urban/industrial cover type[a] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Suburb | Platted suburb | Finger-canal suburb | Golf-course suburb | Indian reserv. | Urban center | Phos. mine | Tita. mine |
| Zone S | | | | | | | | |
| Sand, flatwoods | -1.2** | --- | -4.8** | 1.4** | -3.6** | -2.4** | --- | --- |
| Sand, coastal | --- | --- | -9.8** | --- | --- | --- | --- | --- |
| Rockland, sandy | --- | --- | --- | -1.8** | --- | 1.2** | --- | --- |
| Rockland, marly | -3.2** | --- | --- | --- | --- | --- | --- | --- |
| Organic, muck | --- | --- | --- | --- | --- | -2.4** | --- | --- |

[a] Positive number indicates increase in spring diurnal surface temperature variation mean for urban/industrial cover type compared to that of highest-DSTV natural cover type (mixed scrub in zones P and N, evergreen scrub in zone S).

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

on upland loamy sand, and titanium mine on deep sand all had no substantial difference in DSTV from that of mixed scrub. Other urban/industrial combinations had lower DSTV than did mixed scrub. In zone N in spring, several urban/industrial cover types had AST matching that of the highest-DSTV natural feature, but only urban center on sandy rockland had DSTV exceeding it.

Zone S. Differences in mean DSTV between urban/ industrial cover types and the highest-DSTV natural feature of zone S (evergreen scrub) are given in Table 68. Golf-course suburb on flatwoods sand, and urban center on sandy rockland had higher DSTV than did evergreen scrub. Other urban/ industrial combinations had lower DSTV than did evergreen scrub. In zone S in spring, golf-course suburb on flatwoods sand, and urban center on sandy rockland, had DSTV that exceeded that of the highest-DSTV natural feature.

## Spring Diurnal Change Analyses--Special Factors

Natural factors. Normal and droughty natural land-cover types were compared. As shown in Table 69, droughty bay swamp (mean 16.4 C) had higher DSTV (by 7.6 C) than did normal bay swamp. Droughty mixed swamp (mean 16.8 C) had higher DSTV (by 3.4 C) than did normal mixed swamp. The greater drought-related increase in DSTV for bay swamp than for mixed swamp can be attributed to the organic soil of bay swamp.

Freeze-damaged and normal citrus orchard land-cover were compared. As shown on Table 69, the difference in DSTV

Table 69. Spring diurnal surface temperature variation change for special conditions.

| Zone | Difference in DSTV (C) mean for cover type under special condition[a] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Bay swamp[b] | Mixed swamp[c] | Citrus orchard[d] | Urban center[e] | Cypress swamp[f] | Marsh[g] | Marsh[h] | Flatwoods forest[i] |
| N | 7.6** | 3.4** | 0.8** | --- | --- | --- | --- | --- |
| S | --- | --- | --- | -1.8** | 4.2** | 5.6** | 5.4** | 3.4** |

[a] Positive number indicates increase in spring diurnal surface temperature variation mean for cover type under special condition compared to that of the cover type under normal condition.

[b] Bay swamps under drought condition in north-central Florida (Sandlin Bay and Little Santa Fe Lake area) compared to those under normal condition in central Florida (Chassahowitzka Swamp). See also Mixed Swamp note below.

[c] Mixed swamps under drought condition in north-central Florida and south Georgia (Okeefenokee N.W.R. south of Suwannee R., Pinhook Swamp) compared to those under normal condition in other areas (Okeefenokee N.W.R., north of Suwannee R., Withlacoochee State Forest southeast, Devils Hammock, Hull Cypress Swamp/Bennett Swamp, Spruce Creek Swamp, and Wekiva Swamp). The Okeefenokee N.W.R. hydrology is controlled by a system of dikes and canals along the Suwannee R. Wildfire broke out in the drought-stricken mixed swamp area two months (June 1993) after this image (April 1993).

[d] Citrus orchard (on deep sand) in area heavily damaged by freezes of mid 1980s (Okahumpka/Clermont area) compared to citrus orchard (on deep sand) in areas which had quickly recovered (Ft. Meade, east area and Lake Wales area).

[e] Urban center (Homestead/Leisure City area) on sandy rockland under heavily damaged condition--eight months (April 1993) after Hurricane Andrew (August 1992) compared to nearby urban center on sandy rockland under normal condition (Ft. Lauderdale/Miami).

Table 69--Continued.

[f] Disturbed dwarf-cypress swamp in abandoned platted subdivision (Golden Gate Estates, east area) compared to normal dwarf-cypress swamps nearby (Big Cypress National Preserve--central, southeast, and southwest).

[g] Marsh within the EAA canal system (Holey Land/Rotenberger Wildlife Management Areas) compared to marsh in less-impacted areas (Moonshine Bay area of Lake Okeechobee, Water Conservation Area 2, and Little Doctor Village/Custard Apple Hammock area of the deep Everglades).

[h] Marsh within an area heavily impacted by EAA drainage system (Water Conservation Area 1) compared to marsh in less-impacted areas (Moonshine Bay area of Lake Okeechobee, Water Conservation Area 2, and Little Doctor Village/Custard Apple Hammock area of the deep Everglades).

[i] Flatwoods forest (on flatwoods sand) in West Green Acres area invaded by exotic forest, compared to normal flatwoods forest in other areas (Gator Slough, C. M. Webb WMA, J. W. Corbett WMA, Keri area, and Rainey Slough).

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

between freeze-damaged citrus orchard on deep sand and normal citrus orchard on deep sand was significant, but not substantial. The slight increase in DSTV for the damaged area may be attributed to the loss of tree canopy on abandoned groves, and to decreased canopy on groves converted to pine plantations (very young at image date) and vineyards.

Hurricane-damaged and normal urban/industrial land-cover types were compared. As shown in Table 69, hurricane-damaged urban center on sandy rockland (mean 17.8 C) had lower DSTV (by 1.8 C) than did normal urban center on sandy rockland. This can be attributed to the decrease in the fractional areal occupied by roof-tops after the hurricane (vegetation cover had already returned to the area).

Artificial factors. Disturbed and normal dwarf-cypress land-cover types were compared. As shown in Table 69, disturbed dwarf cypress swamp (mean 15.8 C) had higher DSTV (by 4.2 C) than did normal dwarf cypress swamp.

Disturbed and normal marsh land-cover types were compared. As shown in Table 69, marsh within the Holey Land/Rotenburger Wildlife Management Area of the EAA (mean 13.8 C) had higher DSTV (by 5.6 C) than did normal marsh. As shown in Table 69, marsh within the Water Conservation Area 1 (mean 13.8 C) had higher DSTV (by 5.4 C) than did normal marsh.

Exotic forest and normal flatwoods forest land-cover types were compared. As shown in Table 69, exotic forest (mean 16.0 C) had higher DSTV (by 3.4 C) than did normal

flatwoods forest. These findings for disturbed wetlands and exotic-invaded flatwoods forest indicate that major disturbances (widespread change in vegetation species composition accompanied by/related to major hydrologic alteration) of natural communities appear to increase DSTV.

Winter Afternoon Natural Land-Cover Thermal Patterns

Zone P. Within zone P in winter, eight natural land cover types were present. Listed in order of decreasing mean AST (C), these included mixed scrub (16.2), upland mixed forest (14.8), marsh (14.8), bay swamp (14.8), saltmarsh (14.6), coastal hammock (14.4), flatwoods forest (14.4), and deciduous hardwood swamp (14.0). Differences in mean AST among zone P natural land cover types are given in Table 70; most were significant, and many were substantial. The highest difference (2.2 C) was between mixed scrub and deciduous hardwood swamp. The overall trend was a higher AST for the drier natural land-cover types (mixed scrub, upland mixed forest), and lower AST for the wetter types (marshes and swamps).

Zone N. Within zone N in winter, thirteen natural land cover types were present. Listed in order of decreasing mean AST (C), these included mixed scrub (17.0), marsh (16.4), cypress swamp (16.2), deciduous hardwood swamp (16.2), bay swamp (16.0), evergreen scrub (15.6), coastal hammock (15.4), rockland hammock (15.2), saltmarsh (15.2), upland mixed forest (15.2), mixed swamp (14.8), evergreen hardwood swamp (14.8),

Table 70. Winter afternoon surface temperature differences among natural land-cover types in panhandle zone.

| Natural cover type | Difference in AST (C) mean for natural cover type[a] | | | | | | |
|---|---|---|---|---|---|---|---|
| | SCM | FMX | MRF | SBY | MRS | HCO | FLW |
| FMX | 1.4** | | | | | | |
| MRF | 1.4** | 0.0 | | | | | |
| SBY | 1.4** | 0.0 | 0.0 | | | | |
| MRS | 1.6** | 0.4** | 0.2 | 0.2* | | | |
| HCO | 1.8** | 0.4** | 0.4* | 0.4* | 0.0 | | |
| FLW | 1.8** | 0.4** | 0.4* | 0.4** | 0.0 | 0.0 | |
| SHD | 2.2** | 1.0** | 0.8** | 0.8** | 0.6** | 0.6** | 0.6** |

[a] Positive number indicates increase in spring afternoon surface temperature mean for the natural cover type compared to that of the left-column natural cover type. The natural cover types are denoted as follows: SCM = mixed scrub, FMX = upland mixed forest, MRF = marsh, SBY = bay swamp, MRS = saltmarsh, HCO = coastal hammock, FLW = flatwoods forest, and SHD = deciduous hardwood swamp. These natural cover types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

and flatwoods forest (14.0). Differences in mean AST among zone N natural land cover types are given in Table 71; most were significant, and many were substantial. Among these natural land cover types, the highest difference (3.0 C) in AST was between mixed scrub and flatwoods. The overall trend was a higher AST for the drier natural land-cover types (mixed scrub), and lower AST for the wetter types (marshes and swamps). Mixed scrub had higher AST (by 1.2 C) than did evergreen scrub, which can be attributed to the greater fraction of exposed soil for the deciduous vegetation of mixed scrub in winter. Similarly, deciduous hardwood swamp had higher AST (by 2.4 C) than did evergreen hardwood swamp.

Zone S. Within zone S in winter, fourteen natural land cover types were present. Listed in order of decreasing mean AST (C), these included wet-prairie (19.8), brackish marsh (19.8), dwarf cypress swamp (19.6), rockland hammock (19.4), cypress swamp (19.2), mangrove swamp (19.2), evergreen hardwood swamp (19.0), deciduous shrubby marsh (18.8), mixed swamp (18.8), coastal hammock (18.6), evergreen shrubby marsh (18.6), flatwoods forest (18.4), marsh (18.4), and evergreen scrub (18.4). Differences in mean AST among zone S natural land cover types are given in Table 72; most were significant, but relatively few were substantial. Among these natural land cover types, the highest difference (1.6 C) in AST was between wet-prairie and evergreen scrub. The overall trend was a higher AST for the drier natural land-cover types (wet-prairie, brackish marsh, rockland hammock) and deciduous

Table 71. Winter afternoon surface temperature differences among natural land-cover types in north zone.

| Natural cover type | Difference in AST (C) mean for natural cover type[a] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SCM | MRF | SCY | SHD | SBY | SCE | HCO | HRO | MRS | FMX | SMX | SHE |
| MRF | 0.4** | | | | | | | | | | | |
| SCY | 0.8** | 0.2** | | | | | | | | | | |
| SHD | 0.8** | 0.4** | 0.0 | | | | | | | | | |
| SBY | 1.0** | 0.6** | 0.2** | 0.2* | | | | | | | | |
| SCE | 1.2** | 0.8** | 0.6** | 0.4** | 0.2** | | | | | | | |
| HCO | 1.6** | 1.2** | 0.8** | 0.8** | 0.6** | 0.4** | | | | | | |
| HRO | 1.8** | 1.2** | 1.0** | 1.0** | 0.8** | 0.4** | 0.2* | | | | | |
| MRS | 1.8** | 1.4** | 1.0** | 1.0** | 0.8** | 0.6** | 0.2** | 0.0 | | | | |
| FMX | 1.8** | 1.4** | 1.0** | 1.0** | 0.8** | 0.6** | 0.2** | 0.0 | 0.0 | | | |
| SMX | 2.0** | 1.6** | 1.2** | 1.2** | 1.0** | 0.8** | 0.4** | 0.4** | 0.2** | 0.2* | | |
| SHE | 2.2** | 1.8** | 1.4** | 2.4** | 1.2** | 1.0** | 0.6** | 0.4** | 0.4** | 0.4** | 0.2** | |
| FLW | 3.0** | 2.4** | 2.2** | 3.0** | 2.0** | 1.6** | 1.2** | 1.2** | 1.0** | 1.0** | 0.8** | 0.6** |

[a] Positive number indicates increase in spring afternoon surface temperature mean for the natural cover type compared to that of the left-column natural cover type. The natural cover types are denoted as follows: SCM = mixed scrub, MRF = marsh, SCY = cypress swamp, SHD = deciduous hardwood swamp, SBY = bay swamp, SCE = evergreen scrub, HCO =

Table 71--continued.

coastal hammock, HRO = rockland hammock, MRS = saltmarsh, FMX = upland mixed forest, SMX = mixed swamp, SHE = evergreen hardwood swamp, and FLW = flatwoods forest. These natural cover types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Table 72. Winter afternoon surface temperature differences among natural land-cover types in south zone.

| Nat. cov. type | Difference in AST (C) mean for natural cover type[a] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | MRP | MRS | SCD | HRO | SCY | SMG | SHE | MSD | SMX | HCO | MSE | FLW | MRF |
| MRS | $0.2^{**}$ | | | | | | | | | | | | |
| SCD | $0.2^{**}$ | 0.0 | | | | | | | | | | | |
| HRO | $0.4^{**}$ | $0.4^{**}$ | $0.2^{**}$ | | | | | | | | | | |
| SCY | $0.6^{**}$ | $0.4^{**}$ | $0.4^{**}$ | $0.2^{**}$ | | | | | | | | | |
| SMG | $0.8^{**}$ | $0.6^{**}$ | $0.6^{**}$ | $0.2^{**}$ | $0.2^{*}$ | | | | | | | | |
| SHE | $0.8^{**}$ | $0.8^{**}$ | $0.6^{**}$ | $0.4^{**}$ | $0.2^{**}$ | $0.2^{**}$ | | | | | | | |
| MSD | $1.0^{**}$ | $0.8^{**}$ | $0.8^{**}$ | $0.6^{**}$ | $0.4^{**}$ | $0.2^{**}$ | $0.2^{*}$ | | | | | | |
| SMX | $1.0^{**}$ | $1.0^{**}$ | $0.8^{**}$ | $0.6^{**}$ | $0.4^{**}$ | $0.4^{**}$ | $0.2^{**}$ | 0.0 | | | | | |
| HCO | $1.2^{**}$ | $1.0^{**}$ | $1.0^{**}$ | $0.8^{**}$ | $0.6^{**}$ | $0.4^{**}$ | $0.4^{**}$ | $0.2^{**}$ | $0.2^{**}$ | | | | |
| MSE | $1.4^{**}$ | $1.2^{**}$ | $1.2^{**}$ | $0.8^{**}$ | $0.8^{**}$ | $0.6^{**}$ | $0.4^{**}$ | $0.4^{**}$ | $0.4^{**}$ | $0.2^{*}$ | | | |
| FLW | $1.4^{**}$ | $1.2^{**}$ | $1.2^{**}$ | $1.0^{**}$ | $0.8^{**}$ | $0.6^{**}$ | $0.6^{**}$ | $0.4^{**}$ | $0.4^{**}$ | $0.2^{**}$ | 0.0 | | |
| MRF | $1.4^{**}$ | $1.4^{**}$ | $1.2^{**}$ | $1.0^{**}$ | $0.8^{**}$ | $0.8^{**}$ | $0.6^{**}$ | $0.4^{**}$ | $0.4^{**}$ | $0.2^{**}$ | $0.2^{**}$ | 0.0 | |
| SCE | $1.6^{**}$ | $1.4^{**}$ | $1.4^{**}$ | $1.0^{**}$ | $0.8^{**}$ | $0.8^{**}$ | $0.6^{**}$ | $0.6^{**}$ | $0.4^{**}$ | $0.4^{**}$ | $0.2^{**}$ | 0.2 | 0.0 |

[a] Positive number indicates increase in spring afternoon surface temperature mean for the natural cover type compared to that of the left-column natural cover type. The natural

Table 72--continued.

cover types are denoted as follows: MRP = wet-prairie, MRS = saltmarsh, SCD = dwarf-cypress swamp, HRO = rockland hammock, SCY = cypress swamp, SMG = mangrove swamp, SHE = evergreen hardwood swamp, MSD = deciduous shrubby marsh, SMX = mixed swamp, HCO = coastal hammock, MSE = evergreen shrubby marsh, FLW = flatwoods forest, MRF = marsh, and SCE = evergreen scrub. These natural cover types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

forested types with exposed soil (dwarf cypress swamp, cypress swamp), and lower AST for the wetter types (marsh) and evergreen forested types (flatwoods forest). The relatively high AST of wet-prairie, brackish marsh, and dwarf cypress swamp (all on marly rockland soil) reflects their December dry-season hydrology; the marsh subtype (on muck soil) remains wet throughout the year. There was no substantial difference in DSTV between the evergreen and deciduous subtypes of shrubby marsh, nor between dwarf-cypress swamp and cypress swamp.

Winter Afternoon Agricultural Land-Cover Thermal Patterns

Zone P. Within zone P, there were two types of agriculture distributed on three soil types. Listed in order of decreasing mean AST (C), these agricultural/soil type combinations included mixed agriculture on deep sand (16.0), mixed agriculture on upland loamy sand (15.8), and pasture/range on flatwoods sand (15.4). Differences in mean AST among zone P agricultural/soil type combinations are given in Table 73; all were significant, but none were substantial.

Zone N. Within zone N in winter, there were five agriculture types on up to five different soil types. Listed in order of decreasing mean AST (C), these combinations included citrus orchard on flatwoods sand (20.2), pasture/sod on muck (20.0), row-crops on muck (19.8), citrus orchard on upland loamy sand (19.6), pasture/range on flatwoods sand (19.4), citrus orchard on deep sand (18.8), mixed agriculture

Table 73. Winter afternoon surface temperature differences among agricultural land-cover types in panhandle zone.

| Agricultural cover/soil type | Difference in AST (C) mean for agricultural cover/soil type[a] | |
|---|---|---|
| | AXS | AXU |
| AXU | 0.2** | |
| APF | 0.6** | 0.2** |

[a] Positive number indicates increase in spring afternoon surface temperature mean for the agricultural cover/soil type compared to that of the left-column agricultural cover/soil type. The agricultural cover/soil types are denoted as follows: AXS = mixed agriculture on deep sand, AXU = mixed agriculture on upland loamy sand, and APF = pasture/range on flatwoods sand. These cover/soil types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

on deep sand (18.2), mixed agriculture on flatwoods sand (18.0), mixed agriculture on sandy rockland (17.6), and mixed agriculture on upland loamy sand (17.0). Differences in mean AST among zone N agricultural/soil type combinations are given in Table 74; most were significant, and many were substantial. Among these agricultural land cover types, the highest difference in AST (3.2 C) was between citrus orchard on flatwoods sand and mixed agriculture on upland loamy sand.

Soil type impacts on agricultural type temperatures were compared. Among the mixed agriculture combinations, that on upland loamy sand had lower AST than that on other soil types. Among the pasture combinations, the difference in AST between pasture/sod on muck and pasture/range on flatwoods sand was significant, but not substantial. Among the citrus orchard combinations, that on flatwoods sand had higher AST than did that on deep sand (by 1.4 C). There was no substantial difference in AST between citrus orchards on other soil types. Muck soil agricultural combinations show generally higher AST than other agricultural combinations (except citrus orchard on flatwoods sand), while mixed agriculture combinations with mineral soils show generally lower AST.

Agriculture type impacts on soil type temperatures were compared. Among the deep sand combinations, there was no substantial difference in mean AST between mixed agriculture and citrus orchard. Among the upland loamy sand combinations, citrus orchard had higher AST (by 2.6 C) than did mixed agriculture. Among the flatwoods sand combinations, mixed

Table 74. Winter afternoon surface temperature differences among agricultural land-cover types in north zone.

| Agric. cover/ soil type | Difference in AST (C) mean for agricultural cover/soil type[a] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | ACF | ASM | ARM | ACU | APF | ACS | AXS | AXF | AXR |
| ASM | 0.4** | | | | | | | | |
| ARM | 0.4** | 0.2 | | | | | | | |
| ACU | 0.6** | 0.4** | 0.2 | | | | | | |
| APF | 0.8** | 0.6** | 0.4** | 0.2 | | | | | |
| ACS | 1.4** | 1.2** | 1.0** | 0.8** | 0.8** | | | | |
| AXS | 2.0** | 1.8** | 1.6** | 1.4** | 1.2** | 0.4** | | | |
| AXF | 2.2** | 2.0** | 1.8** | 1.6** | 1.4** | 0.6** | 0.2* | | |
| AXR | 2.6** | 2.4** | 2.2** | 2.0** | 1.8** | 1.2** | 0.6** | 0.4** | |
| AXU | 3.2** | 3.0** | 2.8** | 2.6** | 2.4** | 1.8** | 1.2** | 1.0** | 0.6** |

[a] Positive number indicates increase in spring afternoon surface temperature mean for the agricultural cover/soil type compared to that of the left-column agricultural cover/soil type. The agricultural cover/soil types are denoted as follows: ACF = citrus orchard on flatwoods sand, ASM = pasture/sod on muck, ARM = row-crops on muck, ACU = citrus orchard on upland loamy sand, APF = pasture/range on flatwoods sand, ACS = citrus orchard on deep sand, AXS = mixed agriculture on deep sand, AXF = mixed agriculture on flatwoods sand, AXR = mixed agriculture on sandy rockland, and AXU = mixed agriculture on upland loamy sand. These cover/soil types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

agriculture had lower AST than did either citrus orchard or pasture/range. Among the muck combinations, there was no significant difference between row-crops and pasture/sod. In zone N in winter, differences in AST among certain agricultural types were substantial on some mineral soils, but not on muck.

Zone S. Within zone S, there were five agriculture types on up to six different soil types. Listed in order of decreasing mean AST (C), these combinations included mixed agriculture on marly rockland (20.6), mixed agriculture on sandy rockland (20.4), row-crops on marly rockland (20.2), row-crops on coastal sand (19.4), pasture/range on sandy rockland (19.4), mixed agriculture on flatwoods sand (19.4), pasture/sod on muck (19.2), pasture/range on flatwoods sand (19.0), mixed agriculture on muck (18.8), row-crops on flatwoods sand (18.2), citrus orchard on deep sand (18.0), and citrus orchard on flatwoods sand (17.4). Differences in mean AST among zone S agricultural/soil type combinations are given in Table 75. Among these agricultural land cover types, the highest difference in AST (3.2 C) was between mixed agriculture on marly rockland and citrus orchard on flatwoods sand.

Soil type impacts on agricultural type temperatures were compared. Among the mixed agriculture combinations, the highest difference in AST (1.6 C) was between that on marly rockland and that on muck. Among the row-crop combinations, the highest difference in mean AST (2.0 C) was between that on

Table 75. Winter afternoon surface temperature differences among agricultural land-cover types in south zone.

| Agric. cover/ soil type | Difference in AST (C) mean for agricultural cover/soil type[a] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | AXL | AXR | ARL | ARC | APR | AXF | ASM | APF | AXM | ARF | ACS |
| AXR | 0.2 | | | | | | | | | | |
| ARL | 0.2* | 0.2 | | | | | | | | | |
| ARC | 1.0** | 1.0** | 0.8** | | | | | | | | |
| APR | 1.2** | 1.0** | 0.8** | 0.0 | | | | | | | |
| AXF | 1.2** | 1.0** | 1.0** | 0.2 | 0.0 | | | | | | |
| ASM | 1.4** | 1.2** | 1.0** | 0.4** | 0.2** | 0.2** | | | | | |
| APF | 1.4** | 1.4** | 1.2** | 0.4** | 0.4** | 0.2** | 0.2* | | | | |
| AXM | 1.6** | 1.4** | 1.4** | 0.6** | 0.6** | 0.4** | 0.2** | 0.2** | | | |
| ARF | 2.4** | 2.2** | 2.0** | 1.2** | 1.2** | 1.2** | 1.0** | 0.8** | 0.6** | | |
| ACS | 2.4** | 2.2** | 2.2** | 1.4** | 1.4** | 1.2** | 1.0** | 1.0** | 0.8** | 0.2 | |
| ACF | 3.2** | 3.0** | 2.8** | 2.0** | 2.0** | 1.8** | 1.8** | 1.6** | 1.4** | 0.8** | 0.6** |

[a] Positive number indicates increase in spring afternoon surface temperature mean for the agricultural cover/soil type compared to that of the left-column agricultural cover/soil type. The agricultural cover/soil types are denoted as follows: AXL = mixed agriculture on marly rockland, AXR = mixed agriculture on sandy rockland, ARL = row-crops on marly rockland, ARC = row-crops on coastal sand, APR = pasture/range on sandy rockland, AXF = mixed agriculture on flatwoods sand, ASM = pasture/sod on muck, APF = pasture/range

Table 75--continued.

on flatwoods sand, AXM = mixed agriculture on muck, ARF = row-crops on flatwoods sand, ACS = citrus orchard on deep sand, and ACF = citrus orchard on flatwoods sand. These cover/soil types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

marly rockland and that on flatwoods sand. Among the pasture combinations, there was no substantial difference between pasture/sod on muck and pasture/range on flatwoods sand or on sandy rockland. Among the citrus orchard combinations, there was no substantial difference between that on deep sand and that on flatwoods sand. In zone S in winter, there was a general trend of higher AST for agricultural combinations with marly rockland and sandy rockland.

Agriculture type impacts on soil type temperatures were compared. Among the muck combinations, there was no substantial difference between mixed agriculture and pasture/sod. Among the sandy rockland combinations, mixed agriculture had higher AST (by 1.0 C) than did pasture/range. This was expected, since mixed agriculture includes more exposed soil, and is maintained under a lower water-table condition than is pasture. Among the marly rockland combinations, there was no substantial difference between mixed agriculture and row-crops. Among the flatwoods sand combinations, mixed agriculture had higher AST than did either row-crops or citrus orchard. In zone S in winter, there was a general trend of lower AST for citrus orchard combinations.

Winter Afternoon Urban/Industrial Land-Cover Thermal Patterns

Zone P. Within zone P, there were two types of urban/industrial land cover, distributed on four soil types. Listed in order of decreasing mean AST (C), these included urban center on flatwoods sand (16.8), urban center on deep

sand (16.0), urban center on coastal sand (16.0), urban center on upland loamy sand (15.8), and suburb on coastal sand (15.2). Differences in mean AST among zone P urban/industrial cover/soil type combinations are given in Table 76; most were significant, but few were substantial. Urban center on flatwoods sand had higher mean AST than did that on upland loamy sand and on deep sand. The difference between urban center on coastal sand and suburb on coastal sand was significant, but not substantial. The highest difference in AST (1.6 C) was between urban center on flatwoods sand and suburb on coastal sand.

Zone N. Within zone N, there were six urban/industrial cover types present on five different soil types. Listed in order of decreasing mean AST (C), the combinations included golf-course suburb on flatwoods sand (20.2), suburb on coastal sand (19.8), suburb on flatwoods sand (19.6), urban center on deep sand (19.6), suburb on upland loamy sand (18.8), urban center on flatwoods sand (18.6), suburb on deep sand (18.2), urban center on sandy rockland (17.6), urban center on upland loamy sand (17.4), phosphate mine on flatwoods sand (17.0), suburb on sandy rockland (16.6), titanium mine on deep sand (16.0), and platted suburb on flatwoods sand (15.6). Differences in mean AST among zone N urban/industrial cover/soil type combinations are given in Table 77. Among these land cover types, the highest AST difference (4.6 C) was between golf-course suburb on flatwoods sand and platted suburb on flatwoods sand.

Table 76. Winter afternoon surface temperature differences among urban/industrial land-cover types in panhandle zone.

| Urban/indus. cover/soil type | Difference in AST (C) mean for urban/industrial cover/soil type[a] | | | |
|---|---|---|---|---|
| | UCF | UCS | UCC | UCU |
| UCS | 0.8** | | | |
| UCC | 0.8** | 0.0 | | |
| UCU | 1.0** | 0.2* | 0.2 | |
| USC | 1.6** | 0.8** | 0.8** | 0.6** |

[a] Positive number indicates increase in spring afternoon surface temperature mean for the urban/industrial cover/soil type compared to that of the left-column urban/industrial cover/soil type. The urban/industrial cover/soil types are denoted as follows: UCF = urban center on flatwoods sand, UCS = urban center on deep sand, UCC = urban center on coastal sand, UCU = urban center on upland loamy sand, and USC = suburb on coastal sand. These cover/soil types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Table 77. Winter afternoon surface temperature differences among urban/industrial land-cover types in north zone.

| Urban/ indus. cover/ soil type | Difference in AST (C) mean for urban/industrial cover/soil type[a] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | UGF | USC | USF | UCS | USU | UCF | USS | UCR | UCU | UMF | USR | UMS |
| USC | 0.2 | | | | | | | | | | | |
| USF | 0.6** | 0.2 | | | | | | | | | | |
| UCS | 0.6** | 0.4* | 0.0 | | | | | | | | | |
| USU | 1.4** | 1.2** | 0.8** | 0.8** | | | | | | | | |
| UCF | 1.6** | 1.2** | 1.0** | 1.0** | 0.2 | | | | | | | |
| USS | 2.0** | 1.6** | 1.4** | 1.4** | 0.6** | 0.4** | | | | | | |
| UCR | 2.4** | 2.2** | 1.8** | 1.8** | 1.0** | 0.8** | 0.4** | | | | | |
| UCU | 2.8** | 2.4** | 2.2** | 2.2** | 1.4** | 1.2** | 0.8** | 0.4** | | | | |
| UMF | 3.2** | 2.8** | 2.6** | 2.4** | 1.6** | 1.6** | 1.2** | 0.6** | 0.4** | | | |
| USR | 3.4** | 3.2** | 3.0** | 2.8** | 2.0** | 2.0** | 1.6** | 1.0** | 0.8** | 0.4** | | |
| UMS | 4.2** | 3.8** | 3.6** | 3.6** | 2.8** | 2.6** | 2.2** | 1.8** | 1.4** | 1.0** | 0.6** | |
| UPF | 4.6** | 4.2** | 4.0** | 3.8** | 3.0** | 3.0** | 2.6** | 2.0** | 1.8** | 1.4** | 1.0** | 0.4** |

[a] Positive number indicates increase in spring afternoon surface temperature mean for the urban/industrial cover/soil type compared to that of the left-column urban/industrial cover/soil type. The urban/industrial cover/soil types are denoted as follows: UGF =

Table 77--continued.

golf-course suburb on flatwoods sand, USC = suburb on coastal sand, USF = suburb on flatwoods sand, UCS = urban center on deep sand, USU = suburb on upland loamy sand, UCF = urban center on flatwoods sand, USS = suburb on deep sand, UCR = urban center on sandy rockland, UCU = urban center on upland loamy sand, UMF = phosphate mine on flatwoods sand, USR = suburb on sandy rockland, UMS = titanium mine on deep sand, and UPF = platted suburb on flatwoods sand. These cover/soil types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Soil type impacts on urban/industrial type temperatures were compared. Among the suburb combinations, the highest difference in mean AST (4.6 C) was between golf-course suburb on flatwoods sand and platted suburb on flatwoods sand. Among the urban center combinations, the highest difference in AST (2.2 C) was between urban center on deep sand and that on upland loamy sand. Among the mine combinations, phosphate mine on flatwoods sand had higher AST (by 1.0 C) than did titanium mine on deep sand. In zone N in spring, soil type appears to have a substantial effect on the AST for most urban/industrial land-cover types.

Urban/industrial type impacts on soil type temperatures were compared. Among the deep sand combinations, urban center had higher AST than did suburb (by 1.4 C) or titanium mine (by 3.6 C). Suburb had higher AST (by 2.2 C) than did titanium mine. Among the rockland combinations, urban center had higher AST (by 1.0 C) than did suburb. Among the upland loamy sand combinations, suburb had higher AST (by 1.4 C) than did urban center. Among the flatwoods sand combinations, the highest difference in AST (4.6 C) was between golf-course suburb and platted suburb. Urban center had lower AST than did golf-course suburb (by 1.6 C) or suburb (by 1.0 C), but higher AST than did phosphate mine (by 1.6 C). There was only one cover type present on coastal sand (suburb). In zone N in winter, most urban/industrial cover types had a substantial effect on the AST for a given soil type.

Zone S. Within zone S, there were five urban/industrial cover types present on up to five different soil types. Listed in order of decreasing AST (C) means, the combinations included urban center on sandy rockland (20.8), and finger-canal suburb on coastal sand (20.6), finger-canal suburb on flatwoods sand (20.6), suburb on marly rockland (20.6), golf-course suburb on flatwoods sand (20.2), urban center on flatwoods sand (20.0), golf-course suburb on sandy rockland (19.6), suburb on flatwoods sand (19.4), urban center on muck (18.2), and Indian reservation on flatwoods sand (18.2). Differences in mean AST among zone S urban/industrial cover/soil type combinations are given in Table 78; most were significant, and some were substantial. Among these land cover types, the highest AST difference (2.6 C) was between urban center on sandy rockland and Indian reservation on flatwoods sand.

Soil type impacts on urban/industrial type temperatures were compared. Among the suburb combinations, the highest difference in AST (1.0 C) was between finger-canal suburb on coastal sand and suburb on flatwoods sand. Among the urban center combinations, the highest difference in AST (2.6 C) was between that on sandy rockland and that on muck. In zone S in winter, soil type appears to have a substantial effect on the AST for some suburb and urban center cover types.

Urban/industrial type impacts on soil type temperatures were compared. Among the flatwoods sand combinations, the highest difference in AST (2.4 C) was between finger-canal

Table 78. Winter afternoon surface temperature differences among urban/industrial land-cover types in south zone.

| Urban/indus. cover/soil type | Difference in AST (C) mean for urban/industrial cover/soil type[a] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | UCR | UFC | UFF | USL | UGF | UCF | UGR | USF | UCM |
| UFC | 0.2** | | | | | | | | |
| UFF | 0.2** | 0.0 | | | | | | | |
| USL | 0.4** | 0.0 | 0.0 | | | | | | |
| UGF | 0.6** | 0.4** | 0.4** | 0.4* | | | | | |
| UCF | 0.8** | 0.6** | 0.6** | 0.6** | 0.2* | | | | |
| UGR | 1.2** | 0.8** | 0.8** | 0.8** | 0.6** | 0.4** | | | |
| USF | 1.4** | 1.0** | 1.0** | 1.0** | 0.6** | 0.6** | 0.2 | | |
| UCM | 2.6** | 2.2** | 2.2** | 2.2** | 1.8** | 1.8** | 1.4** | 1.2** | |
| URF | 2.6** | 2.4** | 2.4** | 2.4** | 2.0** | 1.8** | 1.4** | 1.4** | 0.2 |

[a] Positive number indicates increase in spring afternoon surface temperature mean for the urban/industrial cover/soil type compared to that of the left-column urban/industrial cover/soil type. The urban/industrial cover/soil types are denoted as follows: UCR = urban center on sandy rockland, UFC = finger-canal suburb on coastal sand, UFF = finger-canal suburb on flatwoods sand, USL = suburb on marly rockland, UGF = golf-course suburb on flatwoods sand, UCF = urban center on flatwoods sand, UGR = golf-course suburb on sandy rockland, USF = suburb on flatwoods sand, UCM = urban center on muck, and URF = Indian reservation on flatwoods sand. These cover/soil types are further described in the text.

Table 78--continued.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

suburb and Indian reservation. Among the sandy rockland combinations, urban center had higher AST (by 1.2 C) than did golf-course suburb. In zone S in spring, some urban/ industrial cover types appear to have a substantial effect on the AST for a given soil type.

## Winter Afternoon Change Analyses--Natural to Agricultural Land-Cover

Zone P. Differences in mean AST between zone P agricultural/soil type combinations and their original cover types are given in Table 79. Pasture/range on flatwoods sand had higher AST (by 1.0 C) than did the flatwoods forest which was its original land cover. This situation was a reversal of that observed in spring, and can be attributed to seasonal soil moisture fluctuation in the flatwoods forest.

Zone N. Differences in mean AST between zone N agricultural/soil type combinations and their original cover types are given in Table 80. In zone N in winter, there were generally the same trends as in spring, but with increased magnitude.

Zone S. Differences in mean AST between zone S agricultural/soil type combinations and their original cover types are given in Table 81. In zone S in winter, there were generally the same trends as in spring, but with reduced magnitude.

Table 79. Winter afternoon surface temperature change from natural to agricultural in panhandle zone.

| Soil type and natural cover | Difference in AST (C) mean for agricultural cover type[a] | |
|---|---|---|
| | Pasture/range | Mixed |
| Sand, deep (mixed scrub) | --- | -0.2** |
| Sand, loamy (upland mixed forest) | --- | 0.8** |
| Sand, flatwoods (flatwoods forest) | 1.0** | --- |

[a] Positive number indicates increase in spring afternoon surface temperature mean for agricultural cover type compared to that of the natural cover for the soil type.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Table 80. Winter afternoon surface temperature change from natural to agricultural in north zone.

| Soil type and natural cover | Difference in AST (C) mean for agricultural cover type[a] | | | | |
|---|---|---|---|---|---|
| | Row-crops | Pasture/ range | Pasture/ sod | Citrus orchard | Mixed |
| Sand, deep (mixed scrub) | --- | --- | --- | --- | 1.4** |
| Sand, deep (evergreen scrub) | --- | --- | --- | 3.0** | --- |
| Sand, loamy (upland mixed forest) | --- | --- | --- | 4.6** | 2.0** |
| Sand, flatwoods (flatwoods forest) | --- | 5.4** | --- | 6.2** | 4.0** |
| Rockland, sandy (calcareous hammock[b]) | --- | --- | --- | --- | 2.6** |
| Organic, muck (marsh) | 3.4** | --- | 3.6** | --- | --- |

[a] Positive number indicates increase in spring afternoon surface temperature mean for agricultural cover type compared to that of the natural cover for the soil type.

[b] Represented by upland mixed forest.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Table 81. Winter afternoon surface temperature change from natural to agricultural in south zone.

| Soil type and natural cover | Difference in AST (C) mean for agricultural cover type[a] | | | | |
|---|---|---|---|---|---|
| | Row-crops | Pasture/ range | Pasture/ sod | Citrus orchard | Mixed |
| Sand, deep (evergreen scrub) | --- | --- | --- | -0.2** | --- |
| Sand, flatwoods (flatwoods forest) | -0.2** | 0.6** | --- | -1.0** | 0.8** |
| Sand, coastal (coastal hammock) | 0.8** | --- | --- | --- | --- |
| Rockland, sandy (rockland hammock) | --- | 0.0 | --- | --- | 1.0** |
| Rockland, marly (rockland hammock) | 0.8** | --- | --- | --- | 1.0** |
| Organic, muck (marsh) | --- | --- | 0.8** | --- | 0.6** |

[a] Positive number indicates increase in spring afternoon surface temperature mean for agricultural cover type compared to that of the natural cover for the soil type.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Winter Afternoon Change Analyses--Natural to Urban/Industrial Land-Cover

Zone P. Differences in mean AST between zone P urban/industrial cover/soil type combinations and their original cover types are given in Table 82. Within zone P in winter, there were generally the same trends as in spring, but with reduced magnitude (except for the case of urban center on flatwoods sand, which can be attributed to seasonal soil moisture fluctuation in the flatwoods forest).

Zone N. Differences in mean AST between zone N urban/industrial cover/soil type combinations and their original cover types are given in Table 83. In zone N in winter, there were the same general trends as in spring, but with increased magnitude, particularly for suburb land-cover on all soil types and for all urban/industrial types on flatwoods sand. The latter effect can be attributed to seasonal soil moisture fluctuation in the flatwoods forest.

Zone S. Differences in mean AST between zone S urban/industrial soil type combinations and their original cover types are given in Table 84. In zone S in winter, there were the same general trends as in spring, but with mostly decreased magnitude.

Winter Afternoon Change Analyses--Agricultural to Urban/Industrial Land-Cover.

Zone P. Differences in mean AST between zone P urban/industrial cover/soil type combinations and their

Table 82. Winter afternoon surface temperature change from natural to urban/industrial in panhandle zone.

| Soil type and natural cover | Difference in AST (C) mean for urban/industrial cover type[a] | |
|---|---|---|
| | Suburb | Urban center |
| Sand, deep (mixed scrub) | --- | -0.2** |
| Sand, loamy (upland mixed forest) | --- | 0.8** |
| Sand, flatwoods (flatwoods forest) | --- | 2.2** |
| Sand, coastal (coastal hammock) | 0.8** | 1.4** |

[a] Positive number indicates increase in spring afternoon surface temperature mean for urban/industrial cover type compared to that of the natural cover for the soil type.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Table 83. Winter afternoon surface temperature change from natural to urban/industrial in north zone.

| Soil type and natural cover | Difference in AST (C) mean for urban/industrial cover type[a] | | | | | |
|---|---|---|---|---|---|---|
| | Suburb | Platted suburb | Golf-course suburb | Urban center | Phos. mine | Titan. mine |
| Sand, deep (mixed scrub) | --- | --- | --- | --- | --- | $-1.0^{**}$ |
| Sand, deep (evergreen scrub) | $2.6^{**}$ | --- | --- | $3.8^{**}$ | --- | --- |
| Sand, loamy (upland mixed forest) | $3.6^{**}$ | --- | --- | $2.2^{**}$ | --- | --- |
| Sand, flatwoods (flatwoods forest) | $5.6^{**}$ | $1.6^{**}$ | $6.2^{**}$ | $4.6^{**}$ | $3.0^{**}$ | --- |
| Sand, coastal (coastal hammock) | $4.6^{**}$ | --- | --- | --- | --- | --- |
| Rockland, sandy (rockland hammock) | $1.4^{**}$ | --- | --- | --- | --- | --- |
| Rockland, sandy (calcareous hammock[b]) | --- | --- | --- | $2.6^{**}$ | --- | --- |

Table 83--continued.

[a] Positive number indicates increase in spring afternoon surface temperature mean for urban/industrial cover type compared to that of the natural cover for the soil type.

[b] Represented by upland mixed forest.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Table 84. Winter afternoon surface temperature change from natural to urban/industrial in south zone.

| Soil type and natural cover | Difference in AST (C) mean for urban/industrial cover type[a] | | | | |
|---|---|---|---|---|---|
| | Suburb | Finger-canal suburb | Golf-course suburb | Indian reserv. | Urban center |
| Sand, flatwoods (flatwoods forest) | 1.0** | 2.0** | 1.6** | -0.4** | 1.6** |
| Sand, coastal (coastal hammock) | --- | 1.8** | --- | --- | --- |
| Rockland, sandy (rockland hammock) | --- | --- | 0.2* | --- | 1.4** |
| Rockland, marly (rockland hammock) | 1.0** | --- | --- | --- | --- |
| Organic, muck (marsh) | --- | --- | --- | --- | -0.2 |

[a] Positive number indicates increase in spring afternoon surface temperature mean for urban/industrial cover type compared to that of the natural cover for the soil type.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

agricultural counterparts are given in Table 85. Within zone P in winter, there were the same general trends as in spring, but with decreased magnitude.

Zone N. Differences in mean AST between zone N urban/industrial cover/soil type combinations and their agricultural counterparts are given in Table 86. In zone N in winter, there were the same general trends as in spring, but with increased magnitude. An exception in the form of reversal was observed for flatwoods sand combinations, which is attributable to the seasonal soil moisture fluctuation in the flatwoods forest.

Zone S. Differences in mean AST between zone S urban/industrial cover/soil type combinations and their agricultural counterparts are given in Table 87. In zone S in winter, there were the same general trends as in spring, but with decreased magnitude. An exception in form of reversal was observed for flatwoods sand combinations, which is attributable to the seasonal flatwoods forest moisture fluctuation.

### Winter Afternoon Comparison of Agricultural to Natural Heat Islands

Zone P. Differences in mean AST between agricultural cover types and the hottest natural feature of zone P (mixed scrub) are given in Table 88. There were no substantial differences in AST between agricultural types and mixed scrub. Within zone P in winter, all agricultural types had AST

Table 85. Winter afternoon surface temperature change from agricultural to urban/industrial in panhandle zone.

| Soil type and agric. cover | Difference in AST (C) mean for urban/industrial cover type[a] — Urban center |
|---|---|
| Sand, deep (mixed agric.) | 0.0 |
| Sand, loamy (mixed agric.) | 0.0 |
| Sand, flatwoods (pasture/ range) | 1.2** |

[a] Positive number indicates increase in spring afternoon surface temperature mean for urban/industrial cover type compared to that of the agricultural cover for the soil type.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Table 86. Winter afternoon surface temperature change from agricultural to urban/industrial in north zone.

| Soil type and agric. cover | Difference in AST (C) mean for urban/industrial cover type[a] | | | | | |
|---|---|---|---|---|---|---|
| | Suburb | Platted suburb | Golf-course suburb | Urban center | Phos. mine | Tita. mine |
| Sand, deep (citrus orchard) | -0.6** | --- | --- | 0.8** | --- | -2.8** |
| Sand, deep (mixed agric.) | 0.0 | --- | --- | 1.2** | --- | -2.2** |
| Sand, loamy (citrus orchard) | -1.0** | --- | --- | -2.2** | --- | --- |
| Sand, loamy (mixed agric.) | 1.6** | --- | --- | 0.4** | --- | --- |
| Sand, flatwoods (pasture/ range) | 0.2 | -3.8** | 0.6** | -0.8** | -2.4** | --- |
| Sand, flatwoods (citrus orchard) | -0.6** | -4.6** | 0.0 | -1.6** | -3.2** | --- |
| Sand, flatwoods (mixed agric.) | 1.6** | -2.4** | 2.0** | 0.6** | -1.0** | --- |
| Rockland, sandy (mixed agric.) | --- | --- | --- | -0.2 | --- | --- |

Table 86--continued.

[a] Positive number indicates increase in spring afternoon surface temperature mean for urban/industrial cover type compared to that of the agricultural cover for the soil type.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Table 87. Winter afternoon surface temperature change from agricultural to urban/industrial in south zone.

| Soil type | Difference in AST (C) mean for urban/industrial cover type[a] | | | | |
|---|---|---|---|---|---|
| | Suburb | Finger-canal suburb | Golf-course suburb | Indian reserv. | Urban center |
| Sand, flatwoods (row-crops) | 1.2** | 2.4** | 2.0** | 0.0 | 1.8** |
| Sand, flatwoods (pasture/range) | 0.4** | 1.4** | 1.0** | -0.8** | 1.0** |
| Sand, flatwoods (citrus orchard) | 2.0** | 3.0** | 2.8** | 0.8** | 2.6** |
| Sand, flatwoods (mixed agric.) | 0.2** | 1.2** | 0.8** | -1.2** | 0.6** |
| Sand, coastal (row-crops) | --- | 1.0** | --- | --- | --- |
| Rockland, sandy (pasture/range) | --- | --- | 0.2* | --- | 1.4** |
| Rockland, sandy (mixed agric.) | --- | --- | -0.8** | --- | 0.4** |
| Rockland, marly (row-crops) | 0.2 | --- | --- | --- | --- |
| Rockland, marly (mixed agric.) | 0.0 | --- | --- | --- | --- |
| Organic, muck (pasture/sod) | --- | --- | --- | --- | -0.8** |
| Organic, muck (mixed agric.) | --- | --- | --- | --- | -0.6** |

[a] Positive number indicates increase in spring afternoon surface temperature mean for urban/industrial cover type compared to that of the agricultural cover for the soil type.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

matching that of the hottest natural feature, and none had AST exceeding it.

Zone N. Differences in mean AST between agricultural cover types and the hottest natural feature of zone N (mixed scrub) are given in Table 88. Most of the agricultural types had higher AST (by up to 3.2 C) than did mixed scrub. The differences in AST between either mixed agriculture on upland loamy sand or on sandy rockland, and mixed scrub were significant, but not substantial. In zone N in winter, two agricultural combinations matched the AST of the hottest natural feature, while all of the rest had AST that substantially exceeded it.

Zone S. Differences in mean AST between agricultural cover types and the hottest natural feature of zone S (wet-prairie) are given in Table 88. In zone S in winter, several agricultural combinations matched the AST of the hottest natural feature, but none substantially exceeded it.

## Winter Afternoon Comparison of Urban/Industrial to Natural Heat Islands

Zone P. Differences in mean AST between urban/industrial cover types and the hottest natural feature of zone P (mixed scrub) are given in Table 89. Within zone P in winter, nearly all of the urban/industrial combinations matched the AST of the hottest natural feature, but none substantially exceeded it.

Table 88. Winter afternoon surface temperature of agricultural land-cover types vs hottest natural land-cover.

| Soil type | Difference in AST (C) mean for agricultural cover type[a] | | | | |
|---|---|---|---|---|---|
| | Row-crops | Pasture/ range | Pasture/ sod | Citrus orchard | Mixed |
| Zone P | | | | | |
| Sand, deep | --- | --- | --- | --- | -0.2** |
| Sand, loamy | --- | --- | --- | --- | -0.6** |
| Sand, flatwoods | --- | -0.8** | --- | --- | --- |
| Zone N | | | | | |
| Sand, deep | --- | --- | --- | 1.8** | 1.4** |
| Sand, loamy | --- | --- | --- | 2.8** | 0.0 |
| Sand, flatwoods | --- | 2.6** | --- | 3.2** | 1.2** |
| Rockland, sandy | --- | --- | --- | --- | 0.6** |
| Organic, muck | 2.8** | --- | 3.0** | --- | --- |
| Zone S | | | | | |
| Sand, deep | --- | --- | --- | -1.8** | --- |
| Sand, flatwoods | -1.6** | -0.8** | --- | -2.4** | -0.6** |
| Sand, coastal | -0.4** | --- | --- | --- | --- |
| Rockland, sandy | --- | -0.4** | --- | --- | 0.4** |
| Rockland, marly | 0.4** | --- | --- | --- | 0.6** |
| Organic, muck | --- | --- | -0.8** | --- | -1.0** |

[a] Positive number indicates increase in spring afternoon surface temperature mean for agricultural cover type compared to that of hottest natural cover type (mixed scrub in zones P and N, wet-prairie in zone S).

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Table 89. Winter afternoon surface temperature of urban/industrial land-cover types vs hottest natural land-cover.

| | Difference in AST (C) mean for urban/industrial cover type[a] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Soil type | Suburb | Platted suburb | Finger-canal suburb | Golf-course suburb | Indian reserv. | Urban center | Phos. mine | Tita. mine |
| Zone P | | | | | | | | |
| Sand, deep | --- | --- | --- | --- | --- | -0.2** | --- | --- |
| Sand, loamy | --- | --- | --- | --- | --- | -0.4** | --- | --- |
| Sand, flatwoods | --- | --- | --- | --- | --- | 0.4** | --- | --- |
| Sand, coastal | -1.0** | --- | --- | --- | --- | -0.4* | --- | --- |
| Zone N | | | | | | | | |
| Sand, deep | 1.2** | --- | --- | --- | --- | 2.6** | --- | -1.0** |
| Sand, loamy | 1.8** | --- | --- | --- | --- | 0.4** | --- | --- |
| Sand, flatwoods | 2.6** | -1.4** | --- | 3.2** | --- | 1.6** | 0.0 | --- |
| Sand, coastal | 3.0** | --- | --- | --- | --- | --- | --- | --- |
| Rockland, sandy | -0.2* | --- | --- | --- | --- | 0.8** | --- | --- |

Table 89--continued.

| Soil type | Difference in AST (C) mean for urban/industrial cover type[a] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Suburb | Platted suburb | Finger-canal suburb | Golf-course suburb | Indian reserv. | Urban center | Phos. mine | Tita. mine |
| Zone S | | | | | | | | |
| Sand, flatwoods | -0.4** | --- | 0.6** | 0.2** | -1.8** | 0.2* | --- | --- |
| Sand, coastal | --- | --- | 0.6** | --- | --- | --- | --- | --- |
| Rockland, sandy | --- | --- | --- | -0.2** | --- | 1.0** | --- | --- |
| Rockland, marly | 0.6** | --- | --- | --- | --- | --- | --- | --- |
| Organic, muck | --- | --- | --- | --- | --- | -1.6** | --- | --- |

[a] Positive number indicates increase in spring afternoon surface temperature mean for urban/industrial cover type compared to that of hottest natural cover type (mixed scrub in zones P and N, wet-prairie in zone S).

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Zone N. Differences in mean AST between urban/industrial cover types and the hottest natural feature of zone N (mixed scrub) are given in Table 89. In zone N in winter, suburb on sandy rockland, urban center (on upland loamy sand and sandy rockland), and phosphate mine on flatwoods sand matched the AST of the hottest natural feature. Suburb (on all soil types except sandy rockland), golf-course suburb on flatwoods sand, and urban center (on deep sand and flatwoods sand) had AST that substantially exceeded that of the hottest natural feature.

Zone S. Differences in mean AST between urban/industrial cover types and the hottest natural feature of zone S (wet-prairie) are given in Table 89. In zone S in winter, several suburb and urban center types had AST matching that of the hottest natural feature, but only urban center on sandy rockland exceeded it.

## Winter Afternoon Change Analyses--Special Factors

Natural factors. Normal and droughty natural land-cover types were compared. As shown in Table 90, droughty bay swamp (mean 14.0 C) had lower AST (by 1.8 C) than did normal bay swamp. The difference in AST between droughty mixed swamp and normal mixed swamp was not substantial. Since the drought effect for these swamps was evident in the DSTV values, as will be discussed later, this reversal of the trend noted in spring may simply indicate the AST is not as sensitive to

Table 90. Winter afternoon surface temperature change for special conditions.

| Zone | Bay swamp[b] | Mixed swamp[c] | Citrus orchard[d] | Urban center[e] | Cypress swamp[f] | Marsh[g] | Marsh[h] | Flatwoods forest[i] |
|---|---|---|---|---|---|---|---|---|
| | Difference in AST (C) mean for cover type under special condition[a] | | | | | | | |
| N | -1.8** | -0.8** | 1.4** | --- | --- | --- | --- | --- |
| S | --- | --- | --- | -0.4** | 0.0 | 0.0 | -0.4** | -0.4** |

[a] Positive number indicates increase in spring afternoon surface temperature mean for cover type under special condition compared to that of the cover type under normal condition.

[b] Bay swamps under drought condition in north-central Florida (Sandlin Bay and Little Santa Fe Lake area) compared to those under normal condition in central Florida (Chassahowitzka Swamp). See also Mixed Swamp note below.

[c] Mixed swamps under drought condition in north-central Florida and south Georgia (Okeefenokee N.W.R. south of Suwannee R., Pinhook Swamp) compared to those under normal condition in other areas (Okeefenokee N.W.R. north of Suwannee R., Withlacoochee State Forest southeast, Devils Hammock, Hull Cypress Swamp/Bennett Swamp, Spruce Creek Swamp, and Wekiva Swamp). The Okeefenokee N.W.R. hydrology is controlled by a system of dikes and canals along the Suwannee R. Wildfire broke out in the drought-stricken mixed swamp area six months (June 1993) after this image was taken (Dec. 1992).

[d] Citrus orchard (on deep sand) in area heavily damaged by freezes of mid 1980s (Okahumpka/Clermont area) compared to citrus orchard (on deep sand) in areas which had quickly recovered (Ft. Meade, east area and Lake Wales area).

[e] Urban center on sandy rockland, under heavily damaged condition in 1993 images, but under normal condition in this 1989 image, compared to urban center on sandy rockland under normal condition in both 1989 and 1993.

Table 90--Continued.

[f] Disturbed dwarf-cypress swamp in abandoned platted subdivision (Golden Gate Estates, east area) compared to normal dwarf-cypress swamps nearby (Big Cypress National Preserve--central, southeast, and southwest).

[g] Marsh within the EAA canal system (Holey Land/Rotenberger Wildlife Management Areas) compared to marsh in less-impacted areas (Moonshine Bay area of Lake Okeechobee, Water Conservation Area 2, and Little Doctor Village/Custard Apple Hammock area of the deep Everglades).

[h] Marsh within an area heavily impacted by EAA drainage system (Water Conservation Area 1) compared to marsh in less-impacted areas (Moonshine Bay area of Lake Okeechobee, Water Conservation Area 2, and Little Doctor Village/Custard Apple Hammock area of the deep Everglades).

[i] Flatwoods forest (on flatwoods sand) in West Green Acres area invaded by exotic forest, compared to normal flatwoods forest in other areas (Gator Slough, C. M. Webb WMA, J. W. Corbett WMA, Keri area, and Rainey Slough).

[*] Significant at $\alpha = 0.05$.

[**] Significant at $\alpha = 0.01$.

drought condition for evergreen swamp land-cover in winter as it is in spring.

Freeze-damaged and normal citrus orchard land-cover were compared. As shown on Table 90, freeze-damaged citrus orchard on deep sand (mean 20.2 C) had higher AST (by 1.4 C) than did normal citrus orchard on deep sand. This increase in AST for the damaged area may be attributed to the loss of tree canopy on abandoned groves, and to decreased canopy on groves converted to pine plantations (very young at image date) and vineyards.

A check on the pre-hurricane (1989) similarity of the Homestead urban center and normal urban center on sandy rockland was performed. As shown in Table 90, there was no substantial difference in AST between the pre-hurricane Homestead urban center on sandy rockland (mean 20.4 C) and the normal urban center on sandy rockland. This indicates the validity of comparing the two sites under post-hurricane condition.

<u>Artificial factors.</u> Disturbed and normal dwarf-cypress land-cover types were compared. As shown in Table 90, there was no significant difference in AST between disturbed dwarf cypress swamp (mean 19.6 C) and normal dwarf cypress swamp.

Disturbed and normal marsh land-cover types were compared. As shown in Table 90, there was no significant difference in AST between marsh within the Holey Land/ Rotenburger Wildlife Management Area of the EAA (mean 18.4 C) and normal marsh. As shown in Table 90, there was no

significant difference in AST between marsh within the Water Conservation Area 1 (mean 18.0 C) and normal marsh; this may be due to water-storage in WCA-1 for the coming spring dry-season.

Exotic forest and normal flatwoods forest land-cover types were compared. As shown in Table 90, there was no substantial difference in AST between exotic forest (mean 18.0 C) and normal flatwoods forest. These findings for disturbed wetlands and exotic-invaded flatwoods forest indicate that major disturbances (widespread change in vegetation species composition accompanied by/related to major hydrologic alteration) of natural communities appear to produce no substantial increase in winter AST.

Winter Nighttime Natural Land-Cover Thermal Patterns

Zone P. Within zone P in winter, eight natural land cover types were present. Listed in order of decreasing mean NST (C), these included coastal hammock (7.4), deciduous hardwood swamp (5.4), saltmarsh (5.0), marsh (2.8), flatwoods forest (1.6), bay swamp (1.2), upland mixed forest (0.0), and mixed scrub (-1.0). Differences in mean NST among zone P natural land cover types are given in Table 91; most were significant, and many were substantial. The highest difference (8.6 C) was between mixed coastal hammock and mixed scrub. The overall trend was a higher NST for the wetter natural land-cover types (marshes and swamps), and lower NST for the drier types (mixed scrub and upland mixed forest).

Table 91. Winter nighttime surface temperature differences among natural land-cover types in panhandle zone.

| Natural cover type | Difference in NST (C) mean for natural cover type[a] | | | | | | |
|---|---|---|---|---|---|---|---|
| | HCO | SHD | MRS | MRF | FLW | SBY | FMX |
| SHD | 2.2** | | | | | | |
| MRS | 2.4** | 0.2* | | | | | |
| MRF | 4.6** | 2.6** | 2.2** | | | | |
| FLW | 6.0** | 3.8** | 3.6** | 1.4** | | | |
| SBY | 6.2** | 4.2** | 3.8** | 1.6** | 0.2 | | |
| FMX | 7.4** | 5.4** | 5.0** | 2.8** | 1.6** | 1.2** | |
| SCM | 8.6** | 6.4** | 6.2** | 4.0** | 2.6** | 2.4** | 1.0** |

[a] Positive number indicates increase in spring nighttime surface temperature mean for the natural cover type compared to that of the left-column natural cover type. The natural cover types are denoted as follows: HCO = coastal hammock, SHD = deciduous hardwood swamp, MRS = saltmarsh, MRF = marsh, FLW = flatwoods forest, SBY = bay swamp, FMX = upland mixed forest, and SCM = mixed scrub. These natural cover types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Zone N. Within zone N in winter, thirteen natural land cover types were present. Listed in order of decreasing mean NST (C), these included saltmarsh (6.2), marsh (5.8), coastal hammock (5.2), deciduous hardwood swamp (4.8), bay swamp (4.0), cypress swamp (4.0), mixed scrub (2.4), mixed swamp (2.0), evergreen scrub (2.0), rockland hammock (2.0), upland mixed forest (1.4), evergreen hardwood swamp (1.2), and flatwoods forest (1.0). Differences in mean NST among zone N natural land cover types are given in Table 92; most were significant, and many were substantial. Among these natural land cover types, the highest difference (5.2 C) in NST was between saltmarsh and flatwoods forest. The overall trend was a higher NST for the wetter natural land-cover types (swamps and marshes), and lower NST for the drier types (scrub, upland mixed forest). The low NST for flatwoods forest can be attributed to the winter dry season. Differences between evergreen and deciduous subtypes of scrub were significant, but not substantial, indicating that NST is not much affected by defoliation of deciduous trees in winter. Deciduous hardwood swamp had higher NST (by 3.6 C) than did evergreen hardwood swamp, which was expected, since it is a wetter type of swamp. This observation demonstrates the dominance of soil moisture over tree foliage condition in determining winter NST.

Zone S. Within zone S in winter, fourteen natural land cover types were present. Listed in order of decreasing mean NST (C), these included brackish marsh (15.2), mangrove swamp

Table 92. Winter nighttime surface temperature differences among natural land-cover types in north zone.

| Natural cover type | Difference in NST (C) mean for natural cover type[a] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | MRS | MRF | HCO | SHD | SBY | SCY | SCM | SMX | SCE | HRO | FMX | SHE |
| MRF | $0.6^{**}$ | | | | | | | | | | | |
| HCO | $1.0^{**}$ | $0.6^{**}$ | | | | | | | | | | |
| SHD | $1.4^{**}$ | $1.0^{**}$ | $0.4^{**}$ | | | | | | | | | |
| SBY | $2.2^{**}$ | $1.8^{**}$ | $1.2^{**}$ | $0.8^{**}$ | | | | | | | | |
| SCY | $2.4^{**}$ | $1.8^{**}$ | $1.2^{**}$ | $0.8^{**}$ | 0.2 | | | | | | | |
| SCM | $3.8^{**}$ | $3.2^{**}$ | $2.6^{**}$ | $2.4^{**}$ | $1.6^{**}$ | $1.4^{**}$ | | | | | | |
| SMX | $4.2^{**}$ | $3.6^{**}$ | $3.2^{**}$ | $2.8^{**}$ | $2.0^{**}$ | $1.8^{**}$ | $0.4^{**}$ | | | | | |
| SCE | $4.2^{**}$ | $3.8^{**}$ | $3.2^{**}$ | $2.8^{**}$ | $2.0^{**}$ | $1.8^{**}$ | $0.4^{**}$ | 0.0 | | | | |
| HRO | $4.2^{**}$ | $3.8^{**}$ | $3.2^{**}$ | $2.8^{**}$ | $2.0^{**}$ | $1.8^{**}$ | $0.4^{**}$ | 0.0 | 0.0 | | | |
| FMX | $5.0^{**}$ | $4.4^{**}$ | $3.8^{**}$ | $3.4^{**}$ | $2.8^{**}$ | $2.6^{**}$ | $1.2^{**}$ | $0.8^{**}$ | $0.8^{**}$ | $0.6^{**}$ | | |
| SHE | $5.2^{**}$ | $4.6^{**}$ | $4.0^{**}$ | $3.6^{**}$ | $3.0^{**}$ | $2.8^{**}$ | $1.4^{**}$ | $1.0^{**}$ | $1.0^{**}$ | $0.8^{**}$ | $0.2^{*}$ | |
| FLW | $5.2^{**}$ | $4.8^{**}$ | $4.2^{**}$ | $3.8^{**}$ | $3.0^{**}$ | $2.8^{**}$ | $1.4^{**}$ | $1.0^{**}$ | $1.0^{**}$ | $1.0^{**}$ | $0.4^{**}$ | 0.2 |

[a] Positive number indicates increase in spring nighttime surface temperature mean for the natural cover type compared to that of the left-column natural cover type. The natural cover types are denoted as follows: MRS = saltmarsh, MRF = marsh, HCO = coastal hammock, SHD = deciduous hardwood swamp, SBY = bay swamp, SCY = cypress swamp, SCM =

Table 92--Continued.

mixed scrub, SMX = mixed swamp, SCE = evergreen scrub, HRO = rockland hammock, FMX = upland mixed forest, SHE = evergreen hardwood swamp, and FLW = flatwoods forest. These natural cover types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

(15.0), marsh (14.8), coastal hammock (14.6), wet-prairie (14.2), dwarf cypress swamp (13.6), rockland hammock (12.4), deciduous shrubby marsh (12.2), flatwoods forest (12.0), evergreen hardwood swamp (12.0), cypress swamp (11.8), mixed swamp (11.6), evergreen shrubby marsh (11.0), and evergreen scrub (9.4). Differences in mean NST among zone S natural land cover types are given in Table 93; most were significant, and many were substantial. Among these natural land cover types, the highest difference (5.8 C) in NST was between brackish marsh and evergreen scrub. The overall trend was a higher NST for the wetter natural land-cover types (marshes and swamps), and lower NST for the drier types (evergreen scrub). Deciduous shrubby marsh had higher NST (by 1.2 C) than did evergreen shrubby marsh, which can be attributed to the wetter condition of the deciduous shrubby marsh (as indicated by the DSTV which will be discussed later). This observation demonstrates the dominance of soil moisture over tree foliage condition in determining winter NST. Dwarf cypress swamp had higher NST (by 1.8 C) than did cypress swamp. This can be attributed to the wetter condition of the dwarf cypress swamp (as indicated by the DSTV which will be discussed later).

Winter Nighttime Agricultural Land-Cover Thermal Patterns

Zone P. Within zone P, there were two types of agriculture distributed on three soil types. Listed in order of decreasing mean NST (C), these agricultural/soil type

Table 93. Winter nighttime surface temperature differences among natural land-cover types in south zone.

| Nat. cov. type | Difference in NST (C) mean for natural cover type[a] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | MRS | SMG | MRF | HCO | MRP | SCD | HRO | MSD | FLW | SHE | SCY | SMX | MSE |
| SMG | 0.2 | | | | | | | | | | | | |
| MRF | 0.2** | 0.2 | | | | | | | | | | | |
| HCO | 0.6** | 0.4** | 0.4** | | | | | | | | | | |
| MRP | 0.8** | 0.8** | 0.6** | 0.2 | | | | | | | | | |
| SCD | 1.6** | 1.4** | 1.2** | 0.8** | 0.6** | | | | | | | | |
| HRO | 2.6** | 2.6** | 2.4** | 2.0** | 1.8** | 1.2** | | | | | | | |
| MSD | 2.8** | 2.8** | 2.6** | 2.2** | 2.0** | 1.4** | 0.2 | | | | | | |
| FLW | 3.2** | 3.0** | 2.8** | 2.4** | 2.2** | 1.6** | 0.4** | 0.2* | | | | | |
| SHE | 3.2** | 3.2** | 3.0** | 2.6** | 2.4** | 1.8** | 0.6** | 0.4** | 0.2** | | | | |
| SCY | 3.4** | 3.2** | 3.0** | 2.6** | 2.4** | 1.8** | 0.6** | 0.4** | 0.2** | 0.0 | | | |
| SMX | 3.4** | 3.4** | 3.2** | 2.8** | 2.6** | 2.0** | 0.8** | 0.6** | 0.4** | 0.2** | 0.2* | | |
| MSE | 4.2** | 4.0** | 4.0** | 3.6** | 3.2** | 2.6** | 1.4** | 1.2** | 1.0** | 1.0** | 0.8** | 0.8** | |
| SCE | 5.8** | 5.6** | 5.4** | 5.2** | 4.8** | 4.2** | 3.0** | 2.8** | 2.6** | 2.6** | 2.4** | 2.4** | 1.6** |

[a] Positive number indicates increase in spring nighttime surface temperature mean for the natural cover type compared to that of the left-column natural cover type. The natural

Table 93--Continued.

cover types are denoted as follows: MRS = saltmarsh, SMG = mangrove swamp, MRF = marsh, HCO = coastal hammock, MRP = wet-prairie, SCD = dwarf-cypress swamp, HRO = rockland hammock, MSD = deciduous shrubby marsh, FLW = flatwoods forest, SHE = evergreen hardwood swamp, SCY = cypress swamp, SMX = mixed swamp, MSE = evergreen shrubby marsh, and SCE = evergreen scrub. These natural cover types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

combinations included mixed agriculture on upland loamy sand (1.2), mixed agriculture on deep sand (0.4), and pasture/range on flatwoods sand (1.2). Differences in mean NST among zone P agricultural/soil type combinations are given in Table 94; all but one were significant, though none were substantial.

Zone N. Within zone N in winter, there were five agriculture types on up to five different soil types. Listed in order of decreasing mean NST (C), these combinations included row-crops on muck (5.8), mixed agriculture on flatwoods sand (5.6), citrus orchard on deep sand (5.6), pasture/sod on muck (5.4), citrus orchard on flatwoods sand (5.4), pasture/range on flatwoods sand (5.0), citrus orchard on upland loamy sand (3.8), mixed agriculture on deep sand (1.4), mixed agriculture on sandy rockland (0.8), and mixed agriculture on upland loamy sand (0.6). Differences in mean NST among zone N agricultural/soil type combinations are given in Table 95; most were significant, and many were substantial. Among these agricultural land cover types, the highest difference in NST (5.2 C) was between row-crops on muck and mixed agriculture on upland loamy sand.

Soil type impacts on agricultural type temperatures, as well as agriculture type impacts on soil type temperatures, were compared. In zone N in winter, the same general trends were observed as in spring, but with some increases in magnitude.

Table 94. Winter nighttime surface temperature differences among agricultural land-cover types in panhandle zone.

| Agricultural cover/soil type | Difference in NST (C) mean for agricultural cover/soil type[a] | |
|---|---|---|
| | AXU | APF |
| APF | 0.0 | |
| AXS | 0.8** | 0.8** |

[a] Positive number indicates increase in spring nighttime surface temperature mean for the agricultural cover/soil type compared to that of the left-column agricultural cover/soil type. The agricultural cover/soil types are denoted as follows: AXU = mixed agriculture on upland loamy sand, APF = pasture/range on flatwoods sand, and AXS = mixed agriculture on deep sand. These cover/soil types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Table 95. Winter nighttime surface temperature differences among agricultural land-cover types in north zone.

| Agric. cover/ soil type | Difference in NST (C) mean for agricultural cover/soil type[a] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | ARM | AXF | ACS | ASM | ACF | APF | ACU | AXS | AXR |
| AXF | 0.2 | | | | | | | | |
| ACS | 0.2 | 0.0 | | | | | | | |
| ASM | 0.4 | 0.2 | 0.2 | | | | | | |
| ACF | 0.4 | 0.2** | 0.2 | 0.0 | | | | | |
| APF | 0.8** | 0.6** | 0.4** | 0.4 | 0.4** | | | | |
| ACU | 2.0** | 1.6** | 1.6** | 1.4** | 1.4** | 1.2** | | | |
| AXS | 4.4** | 4.2** | 4.2** | 4.0** | 4.0** | 3.6** | 2.6** | | |
| AXR | 5.0** | 4.6** | 4.6** | 4.4** | 4.4** | 4.2** | 3.0** | 0.4** | |
| AXU | 5.2** | 5.0** | 4.8** | 4.8** | 4.8** | 4.4** | 3.2** | 0.8** | 0.2** |

[a] Positive number indicates increase in spring afternoon surface temperature mean for the agricultural cover/soil type compared to that of the left-column agricultural cover/soil type. The agricultural cover/soil types are denoted as follows: ARM = row-crops on muck, AXF = mixed agriculture on flatwoods sand, ACS = citrus orchard on deep sand, ASM = pasture/sod on muck, ACF = citrus orchard on flatwoods sand, APF = pasture/range on flatwoods sand, ACU = citrus orchard on upland loamy sand, AXS = mixed agriculture on deep sand, AXR = mixed agriculture on sandy rockland, and AXU = mixed agriculture on upland loamy sand. These cover/soil types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Zone S. Within zone S, there were five agriculture types on up to six different soil types. Listed in order of decreasing mean NST (C), these combinations included row-crops on coastal sand (14.2), pasture/sod on muck (13.4), mixed agriculture on sandy rockland (12.8), row-crops on marly rockland (12.6), pasture/range on sandy rockland (12.4), mixed agriculture on marly rockland (12.0), row-crops on flatwoods sand (11.8), mixed agriculture on flatwoods sand (11.0), mixed agriculture on muck (10.8), citrus orchard on flatwoods sand (10.6), pasture/range on flatwoods sand (10.4), and citrus orchard on deep sand (9.6). Differences in mean NST among zone S agricultural/soil type combinations are given in Table 96. Among these agricultural land cover types, the highest difference in NST (4.6 C) was between row-crops on coastal sand and citrus orchard on deep sand.

Soil type impacts on agricultural type temperatures, as well as agriculture type impacts on soil type temperatures, were compared. In zone S in winter, the same general trends were observed as in spring.

## Winter Nighttime Urban/Industrial Land-Cover Thermal Patterns

Zone P. Within zone P, there were two types of urban/industrial land cover, distributed on four soil types. Listed in order of decreasing mean NST (C), these included urban center on coastal sand (5.6), urban center on flatwoods sand (3.8), suburb on coastal sand (2.8), urban center on upland loamy sand (1.8), and urban center on deep sand (1.4).

Table 96. Winter nighttime surface temperature differences among agricultural land-cover types in south zone.

| Agric. cover/ soil type | Difference in NST (C) mean for agricultural cover/soil type[a] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | ARC | ASM | AXR | ARL | APR | AXL | ARF | AXF | AXM | ACF | APF |
| ASM | 0.6** | | | | | | | | | | |
| AXR | 1.4** | 0.6** | | | | | | | | | |
| ARL | 1.4** | 0.8** | 0.2 | | | | | | | | |
| APR | 1.8** | 1.2** | 0.4** | 0.4** | | | | | | | |
| AXL | 2.2** | 1.4** | 0.8** | 0.6** | 0.4** | | | | | | |
| ARF | 2.2** | 1.6** | 1.0** | 0.8** | 0.4** | 0.2 | | | | | |
| AXF | 3.2** | 2.4** | 1.8** | 1.6** | 1.4** | 1.0** | 0.8** | | | | |
| AXM | 3.4** | 2.6** | 2.0** | 1.8** | 1.4** | 1.2** | 1.0** | 0.2** | | | |
| ACF | 3.4** | 2.8** | 2.2** | 2.0** | 1.6** | 1.4** | 1.2** | 0.4** | 0.2** | | |
| APF | 3.6** | 3.0** | 2.4** | 2.2** | 1.8** | 1.6** | 1.4** | 0.6** | 0.4** | 0.2** | |
| ACS | 4.6** | 4.0** | 3.2** | 3.0** | 2.8** | 2.4** | 2.4** | 1.4** | 1.2** | 1.2** | 0.8** |

[a] Positive number indicates increase in spring nighttime surface temperature mean for the agricultural cover/soil type compared to that of the left-column agricultural cover/soil type. The agricultural cover/soil types are denoted as follows: ARC = row-crops on coastal sand, ASM = pasture/sod on muck, AXR = mixed agriculture on sandy rockland, ARL = row-crops on marly rockland, APR = pasture/range on sandy rockland, AXL = mixed agriculture on marly rockland, ARF = row-crops on flatwoods sand, AXF = mixed

Table 96--Continued.

agriculture on flatwoods sand, AXM = mixed agriculture on muck, ACF = citrus orchard on flatwoods sand, APF = pasture/range on flatwoods sand, and ACS = citrus orchard on deep sand. These cover/soil types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Differences in mean NST among zone P urban/industrial cover/soil type combinations are given in Table 97; most were significant, and many were substantial. In zone P in winter, the same general trends were observed as in spring.

Zone N. Within zone N, there were six urban/industrial cover types present on five different soil types. Listed in order of decreasing mean NST (C), the combinations included phosphate mine on flatwoods sand (6.8), urban center on deep sand (6.4), golf-course suburb on flatwoods sand (6.4), suburb on flatwoods sand (6.0), urban center on flatwoods sand (6.0), suburb on coastal sand (5.6), suburb on sandy rockland (3.4), titanium mine on deep sand (2.6), urban center on upland loamy sand (2.4), suburb on upland loamy sand (2.2), platted suburb on flatwoods sand (1.6), suburb on deep sand (1.4), and urban center on sandy rockland (1.0). Differences in mean AST among zone N urban/industrial cover/soil type combinations are given in Table 98. Among these land cover types, the highest NST difference (5.8 C) was between phosphate mine on flatwoods sand and urban center on sandy rockland.

Soil type impacts on urban/industrial type temperatures, as well as urban/industrial type impacts on soil type temperatures, were compared. In zone N in winter, the same general trends were observed as in spring.

Zone S. Within zone S, there were five urban/industrial cover types present on up to five different soil types. Listed in order of decreasing NST (C) means, the combinations included finger-canal suburb on coastal sand (15.6), urban

Table 97. Winter nighttime surface temperature differences among urban/industrial land-cover types in panhandle zone.

| Urban/indus. cover/soil type | Difference in NST (C) mean for urban/industrial cover/soil type[a] | | | |
|---|---|---|---|---|
| | UCC | UCF | USC | UCU |
| UCF | 1.8** | | | |
| USC | 2.8** | 1.0** | | |
| UCU | 3.8** | 2.0** | 1.0** | |
| UCS | 4.2** | 2.4** | 1.4** | 0.4** |

[a] Positive number indicates increase in spring nighttime surface temperature mean for the urban/industrial cover/soil type compared to that of the left-column urban/industrial cover/soil type. The urban/industrial cover/soil types are denoted as follows: UCC = urban center on coastal sand, UCF = urban center on flatwoods sand, USC = suburb on coastal sand, UCU = urban center on upland loamy sand, and UCS = urban center on deep sand. These cover/soil types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Table 98. Winter nighttime surface temperature differences among urban/industrial land-cover types in north zone.

| Urban/ indus. cover/ soil type | Difference in NST (C) mean for urban/industrial cover/soil type[a] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | UMF | UCS | UGF | USF | UCF | USC | USR | UMS | UCU | USU | UPF | USS |
| UCS | 0.4* | | | | | | | | | | | |
| UGF | 0.4* | 0.0 | | | | | | | | | | |
| USF | 0.8** | 0.4** | 0.4** | | | | | | | | | |
| UCF | 0.8** | 0.6** | 0.6** | 0.0 | | | | | | | | |
| USC | 1.4** | 1.0** | 1.0** | 0.6** | 0.4** | | | | | | | |
| USR | 3.4** | 3.0** | 3.0** | 2.6** | 2.4** | 2.0** | | | | | | |
| UMS | 4.2** | 4.0** | 3.8** | 3.4** | 3.4** | 3.0** | 0.8* | | | | | |
| UCU | 4.4** | 4.0** | 4.0** | 3.6** | 3.6** | 3.0** | 1.0** | 0.2 | | | | |
| USU | 4.6** | 4.2** | 4.2** | 3.8** | 3.8** | 3.4** | 1.2** | 0.4** | 0.2** | | | |
| UPF | 5.2** | 4.8** | 4.8** | 4.4** | 4.2** | 3.8** | 1.8** | 1.0** | 0.8** | 0.6** | | |
| USS | 5.4** | 5.0** | 5.0** | 4.6** | 4.6** | 4.2** | 2.0** | 1.2** | 1.0** | 0.8** | 0.2 | |
| UCR | 5.8** | 5.4** | 5.4** | 5.0** | 5.0** | 4.4** | 2.4** | 1.6** | 1.4** | 1.2** | 0.6** | 0.4** |

[a] Positive number indicates increase in spring nighttime surface temperature mean for the urban/industrial cover/soil type compared to that of the left-column urban/industrial cover/soil type. The urban/industrial cover/soil types are denoted as follows: UMF =

Table 98--Continued.

phosphate mine on flatwoods sand, UCS = urban center on deep sand, UGF = golf-course suburb on flatwoods sand, USF = suburb on flatwoods sand, UCF = urban center on flatwoods sand, USC = suburb on coastal sand, USR = suburb on sandy rockland, UMS = titanium mine on deep sand, UCU = urban center on upland loamy sand, USU = suburb on upland loamy sand, UPF = platted suburb on flatwoods sand, USS = suburb on deep sand, and UCR = urban center on sandy rockland. These cover/soil types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

center on sandy rockland (13.4), finger-canal suburb on flatwoods sand (13.0), golf-course suburb on sandy rockland (12.8), golf-course suburb on flatwoods sand (12.6), urban center on flatwoods sand (12.2), urban center on muck (12.2), suburb on marly rockland (11.6), suburb on flatwoods sand (11.4), and Indian reservation on flatwoods sand (9.6). Differences in mean NST among zone S urban/industrial cover/soil type combinations are given in Table 99; most were significant, and many were substantial. Among these land cover types, the highest NST difference (6.0 C) was between finger-canal suburb on coastal sand and Indian reservation on flatwoods sand.

Soil type impacts on urban/industrial type temperatures, as well as urban/industrial type impacts on soil type temperatures, were compared. In zone S in winter, the same general trends were observed as in spring.

## Winter Nighttime Change Analyses--Natural to Agricultural Land-Cover

Zone P. Differences in mean NST between zone P agricultural/soil type combinations and their original cover types are given in Table 100. Mixed agriculture had higher NST than did its corresponding natural cover types, while the difference in NST between pasture/range on flatwoods sand and its original cover was significant, but not substantial. Within zone P in winter, conversion from natural to mixed agriculture use appears to increase NST.

Table 99. Winter nighttime surface temperature differences among urban/industrial land-cover types in south zone.

| Urban/ indus. cover/ soil type | Difference in NST (C) mean for urban/industrial cover/soil type[a] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | UFC | UCR | UFF | UGR | UGF | UCF | UCM | USL | USF |
| UCR | 2.2** | | | | | | | | |
| UFF | 2.6** | 0.4** | | | | | | | |
| UGR | 2.8** | 0.6** | 0.2* | | | | | | |
| UGF | 3.0** | 0.8** | 0.4** | 0.2* | | | | | |
| UCF | 3.2** | 1.2** | 0.8** | 0.6** | 0.4** | | | | |
| UCM | 3.4** | 1.2** | 0.8** | 0.6** | 0.4** | 0.0 | | | |
| USL | 4.0** | 1.8** | 1.4** | 1.2** | 1.0** | 0.6** | 0.6** | | |
| USF | 4.2** | 2.0** | 1.6** | 1.4** | 1.2** | 0.8** | 0.8** | 0.2 | |
| URF | 6.0** | 3.8** | 3.4** | 3.2** | 3.0** | 2.6** | 2.6** | 2.0** | 1.8** |

[a] Positive number indicates increase in spring nighttime surface temperature mean for the urban/industrial cover/soil type compared to that of the left-column urban/industrial cover/soil type. The urban/industrial cover/soil types are denoted as follows: UFC = finger-canal suburb on coastal sand, UCR = urban center on sandy rockland, UFF = finger-canal suburb on flatwoods sand, UGR = golf-course suburb on sandy rockland, UGF = golf-course suburb on flatwoods sand, UCF = urban center on flatwoods sand, UCM = urban center on muck, USL = suburb on marly rockland, USF = suburb on flatwoods sand, and URF = Indian reservation on flatwoods sand. These cover/soil types are further described in the text.

Table 99--Continued.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Table 100. Winter nighttime surface temperature change from natural to agricultural in panhandle zone.

| Soil type and natural cover | Difference in NST (C) mean for agricultural cover type[a] | |
| --- | --- | --- |
| | Pasture/range | Mixed |
| Sand, deep (mixed scrub) | --- | 1.6** |
| Sand, loamy (upland mixed forest) | --- | 1.2** |
| Sand, flatwoods (flatwoods forest) | -0.4** | --- |

[a] Positive number indicates increase in spring nighttime surface temperature mean for agricultural cover type compared to that of the natural cover for the soil type.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Zone N. Differences in mean NST between zone N agricultural/soil type combinations and their original cover types are given in Table 101. In winter, the positive trends observed in spring were increased in magnitude, while the negative trends were decreased in magnitude. In zone N in winter, conversion from natural to agricultural cover types appears to produce substantial effects on NST in many cases.

Zone S. Differences in mean AST between zone S agricultural/soil type combinations and their original cover types are given in Table 102. In winter, the trends observed in spring were decreased in magnitude, except for cases involving flatwoods sand and especially muck--for which the magnitudes of the trends remained nearly the same.

### Winter Nighttime Change Analyses--Natural to Urban/Industrial Land-Cover

Zone P. Differences in mean NST between zone P urban/ industrial cover/soil type combinations and their original cover types are given in Table 103. In winter, the same general trends were observed as in spring, but some were increased in magnitude.

Zone N. Differences in mean NST between zone N urban/ industrial cover/soil type combinations and their original cover types are given in Table 104. In winter, the same general trends were observed as in spring, but most were increased in magnitude--especially for urban center

Table 101. Winter nighttime surface temperature change from natural to agricultural in north zone.

| Soil type and natural cover | Difference in NST (C) mean for agricultural cover type[a] | | | | |
|---|---|---|---|---|---|
| | Row-crops | Pasture/ range | Pasture/ sod | Citrus orchard | Mixed |
| Sand, deep (mixed scrub) | --- | --- | --- | --- | -1.2** |
| Sand, deep (evergreen scrub) | --- | --- | --- | 3.4** | --- |
| Sand, loamy (upland mixed forest) | --- | --- | --- | 2.6** | -0.6** |
| Sand, flatwoods (flatwoods forest) | --- | 4.0** | --- | 4.4** | 4.6** |
| Rockland, sandy (calcareous hammock[b]) | --- | --- | --- | --- | -0.4** |
| Organic, muck (marsh) | 0.0 | --- | -0.4 | --- | --- |

[a] Positive number indicates increase in spring nighttime surface temperature mean for agricultural cover type compared to that of the natural cover for the soil type.

[b] Represented by upland mixed forest.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Table 102. Winter nighttime surface temperature change from natural to agricultural in south zone.

| Soil type and natural cover | Difference in NST (C) mean for agricultural cover type[a] | | | | |
|---|---|---|---|---|---|
| | Row-crops | Pasture/range | Pasture/sod | Citrus orchard | Mixed |
| Sand, deep (evergreen scrub) | --- | --- | --- | 0.2 | --- |
| Sand, flatwoods (flatwoods forest) | -0.2* | -1.6** | --- | -1.4** | -1.0** |
| Sand, coastal (coastal hammock) | -0.4 | --- | --- | --- | --- |
| Rockland, sandy (rockland hammock) | --- | -0.2 | --- | --- | 0.4** |
| Rockland, marly (rockland hammock) | 0.2** | --- | --- | --- | -0.4** |
| Organic, muck (marsh) | --- | --- | -1.4** | --- | -4.0** |

[a] Positive number indicates increase in spring nighttime surface temperature mean for agricultural cover type compared to that of the natural cover for the soil type.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Table 103. Winter nighttime surface temperature change from natural to urban/industrial in panhandle zone.

| | Difference in NST (C) mean for urban/industrial cover type[a] | |
|---|---|---|
| Soil type and natural cover | Suburb | Urban center |
| Sand, deep (mixed scrub) | --- | 2.4** |
| Sand, loamy (upland mixed forest) | --- | 1.8** |
| Sand, flatwoods (flatwoods forest) | --- | 2.2** |
| Sand, coastal (coastal hammock) | -4.6** | -1.8** |

[a] Positive number indicates increase in spring nighttime surface temperature mean for urban/industrial cover type compared to that of the natural cover for the soil type.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Table 104. Winter nighttime surface temperature change from natural to urban/industrial in north zone.

| Soil type and natural cover | Difference in NST (C) mean for urban/industrial cover type[a] | | | | | |
|---|---|---|---|---|---|---|
| | Suburb | Platted suburb | Golf-course suburb | Urban center | Phos. mine | Titan. mine |
| Sand, deep (mixed scrub) | --- | --- | --- | --- | --- | 0.0 |
| Sand, deep (evergreen scrub) | -0.6** | --- | --- | 4.4** | --- | --- |
| Sand, loamy (upland mixed forest) | 0.8** | --- | --- | 1.2** | --- | --- |
| Sand, flatwoods (flatwoods forest) | 5.0** | 0.6** | 5.4** | 5.0** | 5.8** | --- |
| Sand, coastal (coastal hammock) | -0.4 | --- | --- | --- | --- | --- |
| Rockland, sandy (rockland hammock) | 1.4 | --- | --- | --- | --- | --- |
| Rockland, sandy (calcareous hammock[b]) | --- | --- | --- | -0.2** | --- | --- |

Table 104--Continued.

[a] Positive number indicates increase in spring nighttime surface temperature mean for urban/industrial cover type compared to that of the natural cover for the soil type.

[b] Represented by upland mixed forest.

[*] Significant at $\alpha = 0.05$.

[**] Significant at $\alpha = 0.01$.

combinations and for all urban/industrial types on flatwoods sand.

Zone S. Differences in mean NST between zone S urban/industrial soil type combinations and their original cover types are given in Table 105. In winter, the same general trends were observed as in spring, although some were changed in magnitude.

### Winter Nighttime Change Analyses--Agricultural to Urban/Industrial Land-Cover.

Zone P. Differences in mean NST between zone P urban/industrial cover/soil type combinations and their agricultural counterparts are given in Table 106. In winter, the same general trends were observed as in spring, but most were decreased in magnitude.

Zone N. Differences in mean NST between zone N urban/industrial cover/soil type combinations and their agricultural counterparts are given in Table 107. In winter, the same general trends were observed as in spring, although many were changed in magnitude.

Zone S. Differences in mean NST between zone S urban/industrial cover/soil type combinations and their agricultural counterparts are given in Table 108. In winter, the same general trends were observed as in spring, although many were changed in magnitude.

Table 105. Winter nighttime surface temperature change from natural to urban/industrial in south zone.

| Soil type and natural cover | Difference in NST (C) mean for urban/industrial cover type[a] | | | | |
|---|---|---|---|---|---|
| | Suburb | Finger-canal suburb | Golf-course suburb | Indian reserv. | Urban center |
| Sand, flatwoods (flatwoods forest) | -0.6** | 1.0** | 0.6** | -2.4** | 0.2* |
| Sand, coastal (coastal hammock) | --- | 1.0** | --- | --- | --- |
| Rockland, sandy (rockland hammock) | --- | --- | 0.4** | --- | 1.0** |
| Rockland, marly (rockland hammock) | -0.8** | --- | --- | --- | --- |
| Organic, muck (marsh) | --- | --- | --- | --- | -2.6** |

[a] Positive number indicates increase in spring nighttime surface temperature mean for urban/industrial cover type compared to that of the natural cover for the soil type.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Table 106. Winter nighttime surface temperature change from agricultural to urban/industrial in panhandle zone.

| Soil type and agric. cover | Difference in NST (C) mean for urban/industrial cover type[a] |
|---|---|
| | Urban center |
| Sand, deep (mixed agric.) | 1.0** |
| Sand, loamy (mixed agric.) | 0.6** |
| Sand, flatwoods (pasture/ range) | 2.6** |

[a] Positive number indicates increase in spring nighttime surface temperature mean for urban/industrial cover type compared to that of the agricultural cover for the soil type.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Table 107. Winter nighttime surface temperature change from agricultural to urban/industrial in north zone.

| Soil type and agric. cover | Difference in NST (C) mean for urban/industrial cover type[a] | | | | | |
|---|---|---|---|---|---|---|
| | Suburb | Platted suburb | Golf-course suburb | Urban center | Phos. mine | Tita. mine |
| Sand, deep (citrus orchard) | -4.2** | --- | --- | 1.0** | --- | -3.0** |
| Sand, deep (mixed agric.) | 0.0 | --- | --- | 5.2** | --- | 1.2** |
| Sand, loamy (citrus orchard) | -1.6** | --- | --- | -1.4** | --- | --- |
| Sand, loamy (mixed agric.) | 1.6** | --- | --- | 1.8** | --- | --- |
| Sand, flatwoods (pasture/ range) | 1.0** | -3.4** | 1.4** | 1.0** | 1.8** | --- |
| Sand, flatwoods (citrus orchard) | 0.6** | -3.8** | 1.2** | 0.6** | 1.4** | --- |
| Sand, flatwoods (mixed agric.) | 0.4** | -4.0** | 0.8** | 0.4** | 1.2** | --- |
| Rockland, sandy (mixed agric.) | --- | --- | --- | 0.2 | --- | --- |

Table 107--Continued.

[a] Positive number indicates increase in spring nighttime surface temperature mean for urban/industrial cover type compared to that of the agricultural cover for the soil type.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Table 108. Winter nighttime surface temperature change from agricultural to urban/industrial in south zone.

| Soil type | Difference in NST (C) mean for urban/industrial cover type[a] | | | | |
|---|---|---|---|---|---|
| | Suburb | Finger-canal suburb | Golf-course suburb | Indian reserv. | Urban center |
| Sand, flatwoods (row-crops) | -0.4** | 1.2** | 0.8** | -2.2** | 0.4** |
| Sand, flatwoods (pasture/range) | 1.0** | 2.6** | 2.2** | -0.8** | 1.8** |
| Sand, flatwoods (citrus orchard) | -4.6** | 2.4** | 2.0** | -1.0** | 1.6** |
| Sand, flatwoods (mixed agric.) | 0.4** | 2.0** | 1.6** | -1.4** | 1.2** |
| Sand, coastal (row-crops) | --- | 1.4** | --- | --- | --- |
| Rockland, sandy (pasture/range) | --- | --- | 0.6** | --- | 1.2** |
| Rockland, sandy (mixed agric.) | --- | --- | 0.0 | --- | 0.6** |
| Rockland, marly (row-crops) | -1.0** | --- | --- | --- | --- |
| Rockland, marly (mixed agric.) | -0.4** | --- | --- | --- | --- |
| Organic, muck (pasture/sod) | --- | --- | --- | --- | -1.2** |
| Organic, muck (mixed agric.) | --- | --- | --- | --- | 1.4** |

[a] Positive number indicates increase in spring nighttime surface temperature mean for urban/industrial cover type compared to that of the agricultural cover for the soil type.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

## Winter Nighttime Comparison of Agricultural to Natural Cold Islands

Zone P. Differences in mean NST between agricultural cover types and the coldest natural feature of zone P (mixed scrub) are given in Table 109. No agricultural combinations were found to match the NST of the coldest natural feature, or to have NST below it.

Zone N. Differences in mean NST between agricultural cover types and the coldest natural feature of zone N (flatwoods forest) are given in Table 109. There was no substantial difference between the NST of the coldest natural feature and that of mixed agriculture on deep sand, upland loamy sand, and sandy rockland. These three cold-island effects matched the NST of the coldest natural feature. No agricultural cold-island effects with substantially lower NST than the coldest natural feature were observed.

Zone S. Differences in mean NST between agricultural cover types and the coldest natural feature of zone S (evergreen scrub) are given in Table 109. There was no substantial difference between the NST of the coldest natural feature and that of citrus orchard on deep sand. This cold-island effect matched the NST of the coldest natural feature. No agricultural cold-island effects with substantially lower NST than the coldest natural feature were observed.

Table 109. Winter nighttime surface temperature of agricultural land-cover types vs coldest natural land-cover.

| Soil type | Row-crops | Pasture/ range | Pasture/ sod | Citrus orchard | Mixed |
|---|---|---|---|---|---|
| | Difference in NST (C) mean for agricultural cover type[a] | | | | |
| Zone P | | | | | |
| Sand, deep | --- | --- | --- | --- | 1.6** |
| Sand, loamy | --- | --- | --- | --- | 2.2** |
| Sand, flatwoods | --- | 2.2** | --- | --- | --- |
| Zone N | | | | | |
| Sand, deep | --- | --- | --- | 4.4** | 0.4** |
| Sand, loamy | --- | --- | --- | 2.8** | -0.4** |
| Sand, flatwoods | --- | 4.0** | --- | 4.4** | 4.6** |
| Rockland, sandy | --- | --- | --- | --- | -0.2** |
| Organic, muck | 4.8** | --- | 4.4** | --- | --- |
| Zone S | | | | | |
| Sand, deep | --- | --- | --- | 0.2 | --- |
| Sand, flatwoods | 2.6** | 1.0** | --- | 1.2** | 1.6** |
| Sand, coastal | 4.8** | --- | --- | --- | --- |
| Rockland, sandy | --- | 3.0** | --- | --- | 3.4** |
| Rockland, marly | 3.2** | --- | --- | --- | 2.6** |
| Organic, muck | --- | --- | 4.2** | --- | 1.4** |

[a] Positive number indicates increase in spring nighttime surface temperature mean for agricultural cover type compared to that of coldest natural cover type (mixed scrub in zone P, flatwoods forest in zone N, evergreen scrub in zone S).

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Winter Nighttime Comparison of Urban/Industrial to Natural Cold Islands

Zone P. Differences in mean NST between urban/industrial cover types and the coldest natural feature of zone P (mixed scrub) are given in Table 110. No urban cold-island effects with substantially lower NST than the coldest natural feature were observed.

Zone N. Differences in mean NST between urban/industrial cover types and the coldest natural feature of zone N (flatwoods forest) are given in Table 110. There was no substantial difference in NST between the coldest natural feature and either suburb on deep sand or platted suburb on flatwoods sand. These two cold-island effects matched the NST of the coldest natural feature. No urban cold-island effects with substantially lower NST than the coldest natural feature were observed.

Zone S. Differences in mean NST between urban/industrial cover types and the hottest natural feature of zone S (evergreen scrub on deep sand) are given in Table 110. There was no substantial difference in NST between the coldest natural feature and Indian reservation on flatwoods sand. This cold-island effect matched the NST of the coldest natural feature. No urban cold-island effects with substantially lower NST than the coldest natural feature were observed.

Table 110. Winter nighttime surface temperature of urban/industrial land-cover types vs coldest natural land-cover.

| Soil type | Difference in NST (C) mean for urban/industrial cover type[a] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Suburb | Platted suburb | Finger-canal suburb | Golf-course suburb | Indian reserv. | Urban center | Phos. mine | Tita. mine |
| Zone P | | | | | | | | |
| Sand, deep | --- | --- | --- | --- | --- | 2.4** | --- | --- |
| Sand, loamy | --- | --- | --- | --- | --- | 3.0** | --- | --- |
| Sand, flatwoods | --- | --- | --- | --- | --- | 4.8** | --- | --- |
| Sand, coastal | 3.8** | --- | --- | --- | --- | 6.8** | --- | --- |
| Zone N | | | | | | | | |
| Sand, deep | 0.4** | --- | --- | --- | --- | 5.4** | --- | 1.6** |
| Sand, loamy | 1.2** | --- | --- | --- | --- | 1.4** | --- | --- |
| Sand, flatwoods | 5.0** | 0.6** | --- | 5.4** | --- | 5.0** | 5.8** | --- |
| Sand, coastal | 4.4** | --- | --- | --- | --- | --- | --- | --- |
| Rockland, sandy | 2.4** | --- | --- | --- | --- | 0.0 | --- | --- |

Table 110--Continued.

| Soil type | Difference in NST (C) mean for urban/industrial cover type[a] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Suburb | Platted suburb | Finger-canal suburb | Golf-course suburb | Indian reserv. | Urban center | Phos. mine | Tita. mine |
| Zone S | | | | | | | | |
| Sand, flatwoods | 2.0** | --- | 3.6** | 3.2** | 0.2 | 2.8** | --- | --- |
| Sand, coastal | --- | --- | 6.2** | --- | --- | --- | --- | --- |
| Rockland, sandy | --- | --- | --- | 3.4** | --- | 4.0** | --- | --- |
| Rockland, marly | 2.2** | --- | --- | --- | --- | --- | --- | --- |
| Organic, muck | --- | --- | --- | --- | --- | 2.8** | --- | --- |

[a] Positive number indicates increase in spring nighttime surface temperature mean for urban/industrial cover type compared to that of coldest natural cover type (mixed scrub in zone P, flatwoods forest in zone N, evergreen scrub in zone S).

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Winter Nighttime Change Analyses--Special Factors

Natural factors. Normal and droughty natural land-cover types were compared. As shown in Table 111, droughty bay swamp (mean 0.2 C) had lower NST (by 4.0 C) than did normal bay swamp. Droughty mixed swamp (mean 0.4 C) had lower NST (by 1.6 C) than did normal mixed swamp. The greater drought-related decrease in NST for bay swamp than for mixed swamp can be attributed to the organic soil of bay swamp.

Freeze-damaged and normal citrus orchard land-cover were compared. As shown on Table 111, the freeze-damaged citrus orchard on deep sand (mean 4.2 C) had lower NST (by 1.2 C) than did normal citrus orchard on deep sand. This decrease in NST for the damaged area may be attributed to the loss of tree canopy on abandoned groves, to decreased canopy on groves converted to pine plantations (very young at image date) and vineyards, and especially to cessation of irrigation.

A check on the pre-hurricane (1989) similarity of the Homestead urban center and normal urban center on sandy rockland was performed. As shown in Table 111, there was no substantial difference in NST between the pre-hurricane Homestead urban center on sandy rockland (mean 12.8 C) and the normal urban center on sandy rockland. This indicates the validity of comparing the two sites under post-hurricane condition.

Artificial factors. Disturbed and normal dwarf-cypress land-cover types were compared. As shown in Table 111, the

Table 111. Winter nighttime surface temperature change for special conditions.

| Zone | Difference in NST (C) mean for cover type under special condition[a] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Bay swamp[b] | Mixed swamp[c] | Citrus orchard[d] | Urban center[e] | Cypress swamp[f] | Marsh[g] | Marsh[h] | Flatwoods forest[i] |
| N | -4.0** | -1.6** | -1.2** | --- | --- | --- | --- | --- |
| S | --- | --- | --- | -0.6** | -3.8** | -2.4** | -0.4** | -0.4** |

[a] Positive number indicates increase in spring nighttime surface temperature mean for cover type under special condition compared to that of the cover type under normal condition.

[b] Bay swamps under drought condition in north-central Florida (Sandlin Bay and Little Santa Fe Lake area) compared to those under normal condition in central Florida (Chassahowitzka Swamp). See also Mixed Swamp note below.

[c] Mixed swamps under drought condition in north-central Florida and south Georgia (Okeefenokee N.W.R. south of Suwannee R., Pinhook Swamp) compared to those under normal condition in other areas (Okeefenokee N.W.R. north of Suwannee R., Withlacoochee State Forest southeast, Devils Hammock, Hull Cypress Swamp/Bennett Swamp, Spruce Creek Swamp, and Wekiva Swamp). The Okeefenokee N.W.R. hydrology is controlled by a system of dikes and canals along the Suwannee R. Wildfire broke out in the drought-stricken mixed swamp area six months (June 1993) after this image (Dec. 1992).

[d] Citrus orchard (on deep sand) in area heavily damaged by freezes of mid 1980s (Okahumpka/Clermont area) compared to citrus orchard (on deep sand) in areas which had quickly recovered (Ft. Meade, east area and Lake Wales area).

[e] Urban center on sandy rockland, heavily damaged in 1993, but under normal condition in this 1989 image, compared to urban center on sandy rockland under normal condition in both 1989 and 1993.

Table 111--Continued.

[f] Disturbed dwarf-cypress swamp in abandoned platted subdivision (Golden Gate Estates, east area) compared to normal dwarf-cypress swamps nearby (Big Cypress National Preserve--central, southeast, and southwest).

[g] Marsh within the EAA canal system (Holey Land/Rotenberger Wildlife Management Areas) compared to marsh in less-impacted areas (Moonshine Bay area of Lake Okeechobee, Water Conservation Area 2, and Little Doctor Village/Custard Apple Hammock area of the deep Everglades).

[h] Marsh within an area heavily impacted by EAA drainage system (Water Conservation Area 1) compared to marsh in less-impacted areas (Moonshine Bay area of Lake Okeechobee, Water Conservation Area 2, and Little Doctor Village/Custard Apple Hammock area of the deep Everglades).

[i] Flatwoods forest (on flatwoods sand) in West Green Acres area invaded by exotic forest, compared to normal flatwoods forest in other areas (Gator Slough, C. M. Webb WMA, J. W. Corbett WMA, Keri area, and Rainey Slough).

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

disturbed dwarf cypress swamp (mean 19.8 C) had much lower NST (by 3.8 C) than did normal dwarf cypress swamp.

Disturbed and normal marsh land-cover types were compared. As shown in Table 111, the Holey Land/Rotenburger Wildlife Management Area of the EAA (mean 12.6 C) had lower NST (by 2.4 C) than did normal marsh. As shown in Table 111, the difference in NST between marsh within the Water Conservation Area 1 (mean 14.4 C) and normal marsh was significant, but not substantial; this may be due to water-storage in WCA-1 for the coming spring dry-season. These findings for disturbed wetlands indicate that major disturbances (widespread change in vegetation species composition accompanied by/related to major hydrologic alteration) of natural communities appear to decrease NST.

Exotic forest and normal flatwoods forest land-cover types were compared. As shown in Table 111, the difference in NST between exotic forest (mean 11.6 C) and normal flatwoods forest was significant, but not substantial.

## Winter Diurnal Natural Land-Cover Thermal Patterns

Zone P. Within zone P in winter, eight natural land cover types were present. Listed in order of decreasing mean DSTV (C), these included mixed scrub (17.4), upland mixed forest (14.8), bay swamp (13.6), flatwoods forest (13.0), marsh (12.0), saltmarsh (9.4), deciduous hardwood swamp (8.6), and coastal hammock (7.0). Differences in mean DSTV among zone P natural land cover types are given in Table 112; most

Table 112. Winter diurnal surface temperature variation differences among natural land-cover types in panhandle zone.

| Natural cover type | Difference in DSTV (C) mean for natural cover type[a] | | | | | | |
|---|---|---|---|---|---|---|---|
| | SCM | FMX | SBY | FLW | MRF | MRS | SHD |
| FMX | 2.4** | | | | | | |
| SBY | 3.8** | 1.4** | | | | | |
| FLW | 4.4** | 1.8** | 0.6 | | | | |
| MRF | 5.4** | 3.0** | 1.6** | 1.0* | | | |
| MRS | 7.8** | 5.4** | 4.0** | 3.6** | 2.4** | | |
| SHD | 8.8** | 6.4** | 5.0** | 4.4** | 3.4** | 1.0** | |
| HCO | 10.2** | 7.8** | 6.6** | 6.0** | 5.0** | 2.4** | 1.6** |

[a] Positive number indicates increase in spring diurnal surface temperature variation mean for the natural cover type compared to that of the left-column natural cover type. The natural cover types are denoted as follows: SCM = mixed scrub, FMX = upland mixed forest, SBY = bay swamp, FLW = flatwoods forest, MRF = marsh, MRS = saltmarsh, SHD = deciduous hardwood swamp, and HCO = coastal hammock. These natural cover types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

were significant, and many were substantial. The highest difference (10.2 C) was between mixed scrub and coastal hammock. The overall trend was a higher DSTV for the drier natural land-cover types (mixed scrub, upland mixed forest), and lower DSTV for the wetter types (marshes and swamps).

Zone N. Within zone N in winter, thirteen natural land cover types were present. Listed in order of decreasing mean DSTV (C), these included mixed scrub (14.4), upland mixed forest (13.8), evergreen scrub (13.6), evergreen hardwood swamp (13.6), rockland hammock (13.2), flatwoods forest (13.0), mixed swamp (12.8), cypress swamp (12.2), bay swamp (11.8), deciduous hardwood swamp (11.4), marsh (10.8), coastal hammock (10.2), and saltmarsh (8.8). Differences in mean DSTV among zone N natural land cover types are given in Table 113; most were significant, and many were substantial. Among these natural land cover types, the highest difference (5.6 C) in DSTV was between mixed scrub and saltmarsh. The overall trend was a higher DSTV for the drier natural land-cover types (mixed scrub, evergreen scrub, upland mixed forest), and lower DSTV for the wetter types (marshes and swamps). Evergreen hardwood swamp had higher DSTV (by 2.2 C) than did deciduous hardwood swamp; this was expected, since evergreen hardwood swamp occupies drier sites than does deciduous hardwood swamp. The difference in DSTV between evergreen and deciduous subtypes of scrub was significant, but not substantial; since it is usually desired to correlate DSTV to soil-moisture without confounding vegetation foliage effects, this

Table 113. Winter diurnal surface temperature variation differences among natural land-cover types in north zone.

| Natural cover type | Difference in DSTV (C) mean for natural cover type[a] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SCM | FMX | SCE | SHE | HRO | FLW | SMX | SCY | SBY | SHD | MRF | HCO |
| FMX | 0.6** | | | | | | | | | | | |
| SCE | 0.8** | 0.2 | | | | | | | | | | |
| SHE | 0.8** | 0.2 | 0.0 | | | | | | | | | |
| HRO | 1.2** | 0.6** | 0.4** | 0.4** | | | | | | | | |
| FLW | 1.4** | 0.8** | 0.6** | 0.6** | 0.2** | | | | | | | |
| SMX | 1.6** | 1.0** | 0.8** | 0.8** | 0.4** | 0.2** | | | | | | |
| SCY | 2.2** | 1.6** | 1.4** | 1.4** | 1.0** | 0.8** | 0.6** | | | | | |
| SBY | 2.6** | 2.0** | 1.8** | 1.6** | 1.2** | 1.2** | 1.0** | 0.4* | | | | |
| SHD | 3.2** | 2.4** | 2.4** | 2.2** | 1.8** | 1.6** | 1.4** | 1.0** | 0.6** | | | |
| MRF | 3.8** | 3.0** | 3.0** | 2.8** | 2.4** | 2.2** | 2.0** | 1.6** | 1.2** | 0.6** | | |
| HCO | 4.4** | 3.6** | 3.4** | 3.4** | 3.0** | 2.8** | 2.6** | 2.2** | 1.8** | 1.2** | 0.6** | |
| MRS | 5.6** | 5.0** | 4.8** | 4.8** | 4.4** | 4.2** | 4.0** | 3.4** | 3.0** | 2.4** | 1.8** | 1.2** |

[a] Positive number indicates increase in spring diurnal surface temperature variation mean for the natural cover type compared to that of the left-column natural cover type. The natural cover types are denoted as follows: SCM = mixed scrub, FMX = upland mixed forest, SCE = evergreen scrub, SHE = evergreen hardwood swamp, HRO = rockland hammock,

Table 113--Continued.

FLW = flatwoods forest, SMX = mixed swamp, SCY = cypress swamp, SBY = bay swamp, SHD = deciduous hardwood swamp, MRF = marsh, HCO = coastal hammock, and MRS = saltmarsh. These natural cover types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

relatively low meso-scale DSTV sensitivity to foliage effects is encouraging.

Zone S. Within zone S in winter, fourteen natural land cover types were present. Listed in order of decreasing mean DSTV (C), these included evergreen scrub (9.0), evergreen shrubby marsh (7.6), cypress swamp (7.4), mixed swamp (7.2), evergreen hardwood swamp (7.2), rockland hammock (7.0), deciduous shrubby marsh (6.6), flatwoods forest (6.4), dwarf cypress swamp (6.0), wet-prairie (5.6), brackish marsh (4.6), coastal hammock (4.2), mangrove swamp (4.2), and marsh (3.6). Differences in mean DSTV among zone S natural land cover types are given in Table 114; most were significant, and many were substantial. Among these natural land cover types, the highest difference (5.4 C) in DSTV was between evergreen scrub and marsh. The overall trend was a higher DSTV for the drier natural land-cover types (evergreen scrub), and lower DSTV for the wetter types (marshes and swamps). Evergreen shrubby marsh had higher DSTV (by 1.0 C) than did deciduous shrubby marsh, which was expected due its drier site characteristics. Cypress swamp had higher DSTV (by 1.4 C) than did dwarf cypress swamp; this can be attributed to the differences in soil type and winter soil moisture between these two swamp subtypes.

## Winter Diurnal Agricultural Land-Cover Thermal Patterns

Zone P. Within zone P, there were two types of agriculture distributed on three soil types. Listed in order

Table 114. Winter diurnal surface temperature variation differences among natural land-cover types in south zone.

| Nat. cov. type | Difference in DSTV (C) mean for natural cover type[a] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SCE | MSE | SCY | SMX | SHE | HRO | MSD | FLW | SCD | MRP | MRS | HCO | SMG |
| MSE | 1.4** | | | | | | | | | | | | |
| SCY | 1.6** | 0.2 | | | | | | | | | | | |
| SMX | 1.8** | 0.4** | 0.4** | | | | | | | | | | |
| SHE | 1.8** | 0.4** | 0.4** | 0.0 | | | | | | | | | |
| HRO | 2.0** | 0.6** | 0.4** | 0.2** | 0.2* | | | | | | | | |
| MSD | 2.4** | 1.0** | 0.8** | 0.6** | 0.4** | 0.4** | | | | | | | |
| FLW | 2.6** | 1.2** | 1.0** | 0.6** | 0.6** | 0.6** | 0.2 | | | | | | |
| SCD | 3.0** | 1.6** | 1.4** | 1.2** | 1.0** | 1.0** | 0.6** | 0.4** | | | | | |
| MRP | 3.4** | 2.0** | 1.8** | 1.6** | 1.4** | 1.4** | 1.0** | 0.8** | 0.4** | | | | |
| MRS | 4.4** | 3.0** | 2.8** | 2.6** | 2.4** | 2.4** | 2.0** | 1.8** | 1.4** | 1.0** | | | |
| HCO | 4.8** | 3.4** | 3.2** | 3.0** | 3.0** | 2.8** | 2.4** | 2.2** | 1.8** | 1.4** | 0.4** | | |
| SMG | 4.8** | 3.4** | 3.4** | 3.0** | 3.0** | 2.8** | 2.6** | 2.4** | 2.0** | 1.6** | 0.4** | 0.0 | |
| MRF | 5.4** | 4.0** | 4.0** | 3.6** | 3.6** | 3.4** | 3.2** | 3.0** | 2.6** | 2.2** | 1.0** | 0.6** | 0.6** |

[a] Positive number indicates increase in spring diurnal surface temperature variation mean for the natural cover type compared to that of the left-column natural cover type. The

Table 114--Continued.

natural cover types are denoted as follows: SCE = evergreen scrub, MSE = evergreen shrubby marsh, SCY = cypress swamp, SMX = mixed swamp, SHE = evergreen hardwood swamp, HRO = rockland hammock, MSD = deciduous shrubby marsh, FLW = flatwoods forest, SCD = dwarf cypress swamp, MRP = wet-prairie, MRS = saltmarsh, HCO = coastal hammock, SMG = mangrove swamp, and MRF = marsh. These natural cover types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

of decreasing mean DSTV (C), these agricultural/soil type combinations included mixed agriculture on deep sand (15.6), mixed agriculture on upland loamy sand (14.6), and pasture/range on flatwoods sand (14.4). Differences in mean DSTV among zone P agricultural/soil type combinations are given in Table 115; all were significant, and most were substantial. The highest difference in DSTV (1.2 C) was between mixed agriculture on deep sand and pasture/range on flatwoods sand. Mixed agriculture on deep sand had higher DSTV (by 1.0 C) than did that on upland loamy sand.

Zone N. Within zone N in winter, there were five agriculture types on up to five different soil types. Listed in order of decreasing mean DSTV (C), these combinations included mixed agriculture on deep sand (16.8), mixed agriculture on sandy rockland (16.8), mixed agriculture on upland loamy sand (16.4), citrus orchard on upland loamy sand (15.8), citrus orchard on flatwoods sand (14.8), pasture/sod on muck (14.6), pasture/range on flatwoods sand (14.4), row-crops on muck (14.0), citrus orchard on deep sand (13.2), and mixed agriculture on flatwoods sand (12.4). Differences in mean DSTV among zone N agricultural/soil type combinations are given in Table 116; most were significant, and many were substantial. Among these agricultural land cover types, the highest difference in DSTV (4.4 C) was between mixed agriculture on deep sand and mixed agriculture on flatwoods sand.

Table 115. Winter diurnal surface temperature variation differences among agricultural land-cover types in panhandle zone.

| Agricultural cover/soil type | Difference in DSTV (C) mean for agricultural cover/soil type[a] | |
|---|---|---|
| | AXS | AXU |
| AXU | 1.0** | |
| APF | 1.2** | 0.2* |

[a] Positive number indicates increase in spring diurnal surface temperature variation mean for the agricultural cover/soil type compared to that of the left-column agricultural cover/soil type. The agricultural cover/soil types are denoted as follows: AXS = mixed agriculture on deep sand, AXU = mixed agriculture on upland loamy sand, and APF = pasture/range on flatwoods sand. These cover/soil types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Table 116. Winter diurnal surface temperature variation differences among agricultural land-cover types in north zone.

| Agric. cover/ soil type | Difference in DSTV (C) mean for agricultural cover/soil type[a] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | AXS | AXR | AXU | ACU | ACF | ASM | APF | ARM | ACS |
| AXR | 0.2 | | | | | | | | |
| AXU | 0.6** | 0.4** | | | | | | | |
| ACU | 1.2** | 1.0** | 0.6** | | | | | | |
| ACF | 2.0** | 1.8** | 1.6** | 1.0** | | | | | |
| ASM | 2.2** | 2.2** | 1.8** | 1.2** | 0.2 | | | | |
| APF | 2.4** | 2.2** | 2.0** | 1.4** | 0.4** | 0.2 | | | |
| ARM | 3.0** | 2.8** | 2.4** | 1.8** | 0.8** | 0.6 | 0.4 | | |
| ACS | 3.6** | 3.4** | 3.2** | 2.6** | 1.6** | 1.4** | 1.2** | 0.8* | |
| AXF | 4.4** | 4.2** | 4.0** | 3.2** | 2.4** | 2.2** | 2.0** | 1.6** | 0.8** |

[a] Positive number indicates increase in spring diurnal surface temperature variation mean for the agricultural cover/soil type compared to that of the left-column agricultural cover/soil type. The agricultural cover/soil types are denoted as follows: AXS = mixed agriculture on deep sand, AXR = mixed agriculture on sandy rockland, AXU = mixed agriculture on upland loamy sand, ACU = citrus orchard on upland loamy sand, ACF = citrus orchard on flatwoods sand, ASM = pasture/sod on muck, APF = pasture/range on flatwoods sand, ARM = row-crops on muck, ACS = citrus orchard on deep sand, and AXF = mixed agriculture on flatwoods sand. These cover/soil types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Soil type impacts on agricultural type temperatures were compared. Among the mixed agriculture combinations, that on flatwoods sand had lower DSTV than that on other soil types. Other differences between mixed agriculture types were significant, but not substantial. Among the pasture combinations, there was no substantial difference in DSTV between pasture/sod on muck and pasture/range on flatwoods sand. Among the citrus orchard combinations, that on upland loamy sand had higher DSTV than did that on either deep sand or flatwoods sand. Citrus orchard on flatwoods sand had higher DSTV than did that on deep sand. In zone N in spring, soil type appears to have substantial effects on the DSTV of some agricultural types.

Agriculture type impacts on soil type temperatures were compared. Among the deep sand combinations, mixed agriculture had higher DSTV (by 3.6 C) than did citrus orchard. Among the upland loamy sand combinations, there was no substantial difference between mixed agriculture and citrus orchard. Among the flatwoods sand combinations, mixed agriculture had lower DSTV than did citrus orchard or pasture/range. Among the muck combinations, there was no substantial difference in DSTV between row-crops and pasture/sod. In zone N in winter, differences in AST among certain agricultural types were substantial on some mineral soils, but not on muck.

<u>Zone S.</u> Within zone S, there were five agriculture types on up to six different soil types. Listed in order of decreasing mean DSTV (C), these combinations included

pasture/range on flatwoods sand (8.6), citrus orchard on deep sand (8.6), mixed agriculture on marly rockland (8.6), mixed agriculture on flatwoods sand (8.4), mixed agriculture on muck (8.0), mixed agriculture on sandy rockland (7.6), row-crops on marly rockland (7.6), pasture/range on sandy rockland (7.2), citrus orchard on flatwoods sand (6.8), row-crops on flatwoods sand (6.4), pasture/sod on muck (5.6), and row-crops on coastal sand (5.4). Differences in mean DSTV among zone S agricultural/soil type combinations are given in Table 117. Among these agricultural land cover types, the highest difference in DSTV (3.2 C) was between pasture/range on flatwoods sand and row-crops on coastal sand.

Soil type impacts on agricultural type temperatures were compared. Among the mixed agriculture combinations, the highest difference in DSTV (1.0 C) was between that on marly rockland and that on sandy rockland. Among the row-crop combinations, the highest difference in mean DSTV (2.2 C) was between that on marly rockland and that on coastal sand. Among the pasture combinations, the highest difference in DSTV (3.0 C) was between pasture/range on flatwoods sand and pasture/sod on muck. Among the citrus orchard combinations, that on deep sand had higher DSTV (by 1.8 C) than did that on flatwoods sand. This was expected, due to the excessively-drained character of the deep sand. In zone S in winter, the DSTV of most agricultural types appears to be substantially affected by soil type.

Table 117. Winter diurnal surface temperature variation differences among agricultural land-cover types in south zone.

| Agric. cover/ soil type | Difference in DSTV (C) mean for agricultural cover/soil type[a] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | APF | ACS | AXL | AXF | AXM | AXR | ARL | APR | ACF | ARF | ASM |
| ACS | 0.0 | | | | | | | | | | |
| AXL | 0.0 | 0.0 | | | | | | | | | |
| AXF | 0.2** | 0.2 | 0.2 | | | | | | | | |
| AXM | 0.6** | 0.4** | 0.4** | 0.2** | | | | | | | |
| AXR | 1.0** | 1.0** | 1.0** | 0.8** | 0.4** | | | | | | |
| ARL | 1.0** | 1.0** | 1.0** | 0.8** | 0.4** | 0.0 | | | | | |
| APR | 1.4** | 1.4** | 1.4** | 1.2** | 1.0** | 0.4** | 0.4** | | | | |
| ACF | 1.8** | 1.8** | 1.8** | 1.6** | 1.2** | 0.8** | 0.8** | 0.4** | | | |
| ARF | 2.2** | 2.2** | 2.2** | 2.0** | 1.8** | 1.2** | 1.2** | 0.8** | 0.4** | | |
| ASM | 3.0** | 2.8** | 2.8** | 2.6** | 2.4** | 2.0** | 2.0** | 1.4** | 1.0** | 0.6** | |
| ARC | 3.2** | 3.2** | 3.2** | 3.0** | 2.8** | 2.2** | 2.2** | 1.8** | 1.4** | 1.0** | 0.4 |

[a] Positive number indicates increase in spring diurnal surface temperature variation mean for the agricultural cover/soil type compared to that of the left-column agricultural cover/soil type. The agricultural cover/soil types are denoted as follows: APF = pasture/range on flatwoods sand, ACS = citrus orchard on deep sand, AXL = mixed agriculture on marly rockland, AXF = mixed agriculture on flatwoods sand, AXM = mixed agriculture on muck, AXR = mixed agriculture on sandy rockland, ARL = row-crops on marly

Table 117--Continued.

rockland, APR = pasture/range on sandy rockland, ACF = citrus orchard on flatwoods sand, ARF = row-crops on flatwoods sand, ASM = pasture/sod on muck, and ARC = row-crops on coastal sand. These cover/soil types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Agriculture type impacts on soil type temperatures were compared. Among the muck combinations, mixed agriculture had higher DSTV (by 2.4 C) than did pasture/sod. This was expected, since mixed agriculture includes more exposed soil, and is maintained under a lower water-table condition than is pasture. Among the sandy rockland combinations, there was no substantial difference between mixed agriculture and pasture/range. Among the marly rockland combinations, mixed agriculture had higher DSTV (by 1.0 C) than did row-crops. This was expected, since mixed agriculture is maintained under a lower water-table condition than are row-crops. Among the flatwoods sand combinations, mixed agriculture had higher DSTV (by 2.0 C) than did row-crops; this was expected, since mixed agriculture is maintained under a lower water-table condition than row-crops. In zone S in winter, agriculture types appeared to increase DSTV on most soil types.

Winter Diurnal Urban/Industrial Land-Cover Thermal Patterns

Zone P. Within zone P, there were two types of urban/industrial land cover, distributed on four soil types. Listed in order of decreasing mean DSTV (C), these included urban center on deep sand (14.6), urban center on upland loamy sand (14.0), urban center on flatwoods sand (13.0), suburb on coastal sand (12.4), and urban center on coastal sand (10.4). Differences in mean DSTV among zone P urban/ industrial cover/soil type combinations are given in Table 118; most were significant, and many were substantial. The highest

Table 118. Winter diurnal surface temperature variation differences among urban/industrial land-cover types in panhandle zone.

| Urban/indus. cover/soil type | Difference in DSTV (C) mean for urban/industrial cover/soil type[a] | | | |
|---|---|---|---|---|
| | UCS | UCU | UCF | USC |
| UCU | 0.8** | | | |
| UCF | 1.8** | 1.0* | | |
| USC | 2.2** | 1.6** | 0.6 | |
| UCC | 4.4** | 3.6** | 2.6** | 2.2** |

[a] Positive number indicates increase in spring diurnal surface temperature variation mean for the urban/industrial cover/ soil type compared to that of the left-column urban/ industrial cover/soil type. The urban/industrial cover/soil types are UCS = urban center on deep sand, UCU = urban center on upland loamy sand, UCF = urban center on flatwoods sand, USC = suburb on coastal sand, and UCC = urban center on coastal sand. These cover/soil types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

difference in DSTV (4.4 C) was between urban center on deep sand and urban center on coastal sand. Suburb on coastal sand had higher DSTV (by 2.2 C) than did urban center on coastal sand.

Zone N. Within zone N, there were six urban/industrial cover types present on five different soil types. Listed in order of decreasing mean DSTV (C), the combinations included suburb on deep sand (16.8), urban center on sandy rockland (16.6), suburb on upland loamy sand (16.6), urban center on upland loamy sand (15.0), suburb on coastal sand (14.4), platted suburb on flatwoods sand (14.0), golf-course suburb on flatwoods sand (13.6), suburb on flatwoods sand (13.6), titanium mine on deep sand (13.4), suburb on sandy rockland (13.2), urban center on deep sand (13.0), urban center on flatwoods sand (12.6), and phosphate mine on flatwoods sand (10.2). Differences in mean DSTV among zone N urban/industrial cover/soil type combinations are given in Table 119. Among these land cover types, the highest DSTV difference (6.6 C) was between suburb on deep sand and phosphate mine on flatwoods sand.

Soil type impacts on urban/industrial type temperatures were compared. Among the suburb combinations, the highest difference in mean DSTV (3.6 C) was between suburb on deep sand and that on sandy rockland. Among the urban center combinations, the highest difference in DSTV (4.0 C) was between that on sandy rockland and that on flatwoods sand. The differences between most of the urban center combinations

Table 119. Winter diurnal surface temperature variation differences among urban/industrial land-cover types in north zone.

| Urban/ indus. cover/ soil type | Difference in DSTV (C) mean for urban/industrial cover/soil type[a] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | USS | UCR | USU | UCU | USC | UPF | UGF | USF | UMS | USR | UCS | UCF |
| UCR | 0.2 | | | | | | | | | | | |
| USU | 0.2* | 0.2 | | | | | | | | | | |
| UCU | 1.8** | 1.8** | 1.6** | | | | | | | | | |
| USC | 2.4** | 2.2** | 2.2** | 0.6* | | | | | | | | |
| UPF | 2.8** | 2.6** | 2.6** | 1.0** | 0.4 | | | | | | | |
| UGF | 3.2** | 3.0** | 2.8** | 1.2** | 0.6* | 0.2 | | | | | | |
| USF | 3.2** | 3.0** | 3.0** | 1.4** | 0.8** | 0.4* | 0.2 | | | | | |
| UMS | 3.4** | 3.2** | 3.2** | 1.6** | 1.0** | 0.6** | 0.2 | 0.2 | | | | |
| USR | 3.6** | 3.4** | 3.4** | 1.8** | 1.2** | 0.8** | 0.4 | 0.4 | 0.2 | | | |
| UCS | 3.8** | 3.6** | 3.4** | 2.0** | 1.4** | 1.0** | 0.6** | 0.6** | 0.4* | 0.2 | | |
| UCF | 4.2** | 4.0** | 3.8** | 2.2** | 1.8** | 1.4** | 1.0** | 1.0** | 0.8** | 0.6 | 0.4** | |
| UMF | 6.6** | 6.4** | 6.4** | 4.8** | 4.2** | 3.8** | 3.4** | 3.4** | 3.2** | 3.0** | 2.8** | 2.4** |

[a] Positive number indicates increase in spring diurnal surface temperature variation mean for the urban/industrial cover/soil type compared to that of the left-column urban/industrial cover/soil type. The urban/industrial cover/soil types are denoted as follows: USS =

Table 119--Continued.

suburb on deep sand, UCR = urban center on sandy rockland, USU = suburb on upland loamy sand, UCU = urban center on upland loamy sand, USC = suburb on coastal sand, UPF = platted suburb on flatwoods sand, UGF = golf-course suburb on flatwoods sand, USF = suburb on flatwoods sand, UMS = titanium mine on deep sand, USR = suburb on sandy rockland, UCS = urban center on deep sand, UCF = urban center on flatwoods sand, and UMF = phosphate mine on flatwoods sand. These cover/soil types are further described in the text.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

were substantial. Among the mine combinations, titanium mine on deep sand had higher DSTV (by 3.2 C) than did phosphate mine on flatwoods sand, which can be attributed to the presence of settling ponds within phosphate mine. In zone N in spring, soil type appears to have a substantial effect on the DSTV for all urban/industrial types.

Urban/industrial type impacts on soil type temperatures were compared. Among the deep sand combinations, suburb had higher DSTV than did urban center (by 3.8 C). Among the rockland combinations, urban center had higher DSTV (by 3.4 C) than did suburb. Among the upland loamy sand combinations, suburb had higher DSTV (by 1.6 C) than did urban center. Among the flatwoods sand combinations, urban center had lower DSTV than did the other urban/industrial types. There was only one cover type present on coastal sand (suburb). In zone N in winter, most urban/industrial cover types had a substantial effect on the DSTV for a given soil type.

Zone S. Within zone S, there were five urban/industrial cover types present on up to five different soil types. Listed in order of decreasing DSTV (C) means, the combinations included suburb on marly rockland (8.8), Indian reservation on flatwoods sand (8.6), suburb on flatwoods sand (8.0), urban center on flatwoods sand (7.8), golf-course suburb on flatwoods sand (7.6), finger-canal suburb on flatwoods sand (7.4), urban center on sandy rockland (7.4), golf-course suburb on sandy rockland (6.8), urban center on muck (6.0), and finger-canal suburb on coastal sand (5.0). Differences in

mean DSTV among zone S urban/industrial cover/soil type combinations are given in Table 120; most were significant, and many were substantial. Among these land cover types, the highest DSTV difference (4.0 C) was between suburb on marly rockland and finger-canal suburb on coastal sand.

Soil type impacts on urban/industrial type temperatures were compared. Among the suburb combinations, the highest difference in DSTV (4.0 C) was between suburb on marly rockland and finger-canal suburb on coastal sand. Among the finger-canal suburbs, that on flatwoods sand had higher DSTV (by 2.6 C) than did that on coastal sand. Among the golf-course suburbs, there was no substantial difference between that on flatwoods sand and that on sandy rockland. Among the urban center combinations, that on muck had lower DSTV than did that on either flatwoods sand or sandy rockland. In zone S in winter, soil type appears to have a substantial effect on the DSTV for urban/industrial land-cover types.

Urban/industrial type impacts on soil type temperatures were compared. Among the flatwoods sand combinations, the highest difference in DSTV (1.0 C) was between Indian reservation and finger-canal suburb. Among the sandy rockland combinations, there was no substantial difference between urban center and golf-course suburb. In zone S in winter, urban/industrial cover type appears to have a substantial effect on the DSTV for some soil types.

Table 120. Winter diurnal surface temperature variation differences among urban/industrial land-cover types in south zone.

| Urban/ indus. cover/ soil type | Difference in DSTV (C) mean for urban/industrial cover/soil type[a] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | USL | URF | USF | UCF | UGF | UFF | UCR | UGR | UCM |
| URF | 0.4 | | | | | | | | |
| USF | 0.8** | 0.4** | | | | | | | |
| UCF | 1.2** | 0.8** | 0.4** | | | | | | |
| UGF | 1.4** | 1.0** | 0.6** | 0.2 | | | | | |
| UFF | 1.4** | 1.0** | 0.6** | 0.2* | 0.0 | | | | |
| UCR | 1.4** | 1.2** | 0.6** | 0.4** | 0.2* | 0.0 | | | |
| UGR | 2.0** | 1.8** | 1.2** | 1.0** | 0.8** | 0.6** | 0.6** | | |
| UCM | 2.8** | 2.6** | 2.0** | 1.6** | 1.6** | 1.4** | 1.4** | 0.8** | |
| UFC | 4.0** | 3.6** | 3.2** | 2.8** | 2.6** | 2.6** | 2.4** | 1.8** | 1.0** |

[a] Positive number indicates increase in spring diurnal surface temperature variation mean for the urban/industrial cover/soil type compared to that of the left-column urban/industrial cover/soil type. The urban/industrial cover/soil types are denoted as follows: USL = suburb on marly rockland, URF = Indian reservation on flatwoods sand, USF = suburb on flatwoods sand, UCF = urban center on flatwoods sand, UGF = golf-course suburb on flatwoods sand, UFF = finger-canal suburb on flatwoods sand, UCR = urban center on sandy rockland, UGR = golf-course suburb on sandy rockland, UCM = urban center on muck, and UFC = finger-canal suburb on coastal sand. These cover/soil types are further described in the text.

Table 120--Continued.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

## Winter Diurnal Change Analyses--Natural to Agricultural Land-Cover

Zone P. Differences in mean DSTV between zone P agricultural/soil type combinations and their original cover types are given in Table 121. The trends observed in spring were reversed. This can be attributed to differences in seasonal irrigation practices.

Zone N. Differences in mean DSTV between zone N agricultural/soil type combinations and their original cover types are given in Table 122. Many of the trends observed in spring were reversed. This can be attributed to differences in seasonal irrigation practices.

Zone S. Differences in mean DSTV between zone S agricultural/soil type combinations and their original cover types are given in Table 123. The general trends observed in spring were mostly reduced in magnitude. Exceptions were on muck--where the change in DSTV remained high for both pasture/sod and mixed agriculture, and on flatwoods sand--where the change in DSTV increased in magnitude for mixed agriculture.

## Winter Diurnal Change Analyses--Natural to Urban/Industrial Land-Cover

Zone P. Differences in mean DSTV between zone P urban/ industrial cover/soil type combinations and their original cover types are given in Table 124. The trends observed in spring were reversed for urban center on deep sand and on

Table 121. Winter diurnal surface temperature variation change from natural to agricultural in panhandle zone.

| Soil type and natural cover | Difference in DSTV (C) mean for agricultural cover type[a] | |
|---|---|---|
| | Pasture/range | Mixed |
| Sand, deep (mixed scrub) | --- | -1.8** |
| Sand, loamy (upland mixed forest) | --- | -0.4** |
| Sand, flatwoods (flatwoods forest) | 1.4** | --- |

[a] Positive number indicates increase in spring diurnal surface temperature variation mean for agricultural cover type compared to that of the natural cover for the soil type.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Table 122. Winter diurnal surface temperature variation change from natural to agricultural in north zone.

| Soil type and natural cover | Difference in DSTV (C) mean for agricultural cover type[a] | | | | |
|---|---|---|---|---|---|
| | Row-crops | Pasture/range | Pasture/sod | Citrus orchard | Mixed |
| Sand, deep (mixed scrub) | --- | --- | --- | --- | 2.4** |
| Sand, deep (evergreen scrub) | --- | --- | --- | -0.4** | --- |
| Sand, loamy (upland mixed forest) | --- | --- | --- | 2.0** | -2.6** |
| Sand, flatwoods (flatwoods forest) | --- | 1.4** | --- | 1.8** | -0.6** |
| Rockland, sandy (calcareous hammock[b]) | --- | --- | --- | --- | 3.0** |
| Organic, muck (marsh) | 3.2** | --- | 3.8** | --- | --- |

[a] Positive number indicates increase in spring diurnal surface temperature variation mean for agricultural cover type compared to that of the natural cover for the soil type.

[b] Represented by upland mixed forest.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Table 123. Winter diurnal surface temperature variation change from natural to agricultural in south zone.

| Soil type and natural cover | Difference in DSTV (C) mean for agricultural cover type[a] | | | | |
|---|---|---|---|---|---|
| | Row-crops | Pasture/range | Pasture/sod | Citrus orchard | Mixed |
| Sand, deep (evergreen scrub) | --- | --- | --- | -0.4* | --- |
| Sand, flatwoods (flatwoods forest) | -0.2 | 2.2** | --- | 0.2** | 6.0** |
| Sand, coastal (coastal hammock) | 1.2** | --- | --- | --- | --- |
| Rockland, sandy (rockland hammock) | --- | 0.2 | --- | --- | 0.6** |
| Rockland, marly (rockland hammock) | 0.6** | --- | --- | --- | 1.6** |
| Organic, muck (marsh) | --- | --- | 2.2** | --- | 4.6** |

[a] Positive number indicates increase in spring diurnal surface temperature variation mean for agricultural cover type compared to that of the natural cover for the soil type.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Table 124. Winter diurnal surface temperature variation change from natural to urban/industrial in panhandle zone.

| Soil type and natural cover | Difference in DSTV (C) mean for urban/industrial cover type[a] | |
|---|---|---|
| | Suburb | Urban center |
| Sand, deep (mixed scrub) | --- | -2.6** |
| Sand, loamy (upland mixed forest) | --- | -1.0** |
| Sand, flatwoods (flatwoods forest) | --- | 0.0 |
| Sand, coastal (coastal hammock) | 5.4** | 3.2** |

[a] Positive number indicates increase in spring diurnal surface temperature variation mean for urban/industrial cover type compared to that of the natural cover for the soil type.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

upland loamy sand, decreased in magnitude for urban center on flatwoods sand, and increased in magnitude for suburb on coastal sand. These effects can be attributed to seasonal changes in soil moisture for the natural cover types.

Zone N. Differences in mean DSTV between zone N urban/industrial cover/soil type combinations and their original cover types are given in Table 125. There were many changes in the trends observed in spring. The most notable of these changes was the increase in the magnitude of the DSTV trends for normal suburb on most soils (except sandy rockland). This can be attributed to the curtailing of lawn and ornamental irrigation in winter. The increase in magnitude of the trends for mines, as well as the decrease in magnitude of the trends for urban center on most soil types, can be attributed to seasonal changes in soil moisture for the natural cover types.

Zone S. Differences in mean DSTV between zone S urban/industrial soil type combinations and their original cover types are given in Table 126. The general trends observed in spring were decreased in magnitude. An exception was the increase in the magnitude of the DSTV effect of suburb on marly rockland compared to its original land-cover.

### Winter Diurnal Change Analyses--Agricultural to Urban/Industrial Land-Cover.

Zone P. Differences in mean DSTV between zone P urban/industrial cover/soil type combinations and their agricultural

Table 125. Winter diurnal surface temperature variation change from natural to urban/industrial in north zone.

| Soil type and natural cover | Difference in DSTV (C) mean for urban/industrial cover type[a] | | | | | |
|---|---|---|---|---|---|---|
| | Suburb | Platted suburb | Golf-course suburb | Urban center | Phos. mine | Titan. mine |
| Sand, deep (mixed scrub) | --- | --- | --- | --- | --- | -1.0** |
| Sand, deep (evergreen scrub) | 3.2** | --- | --- | -0.6** | --- | --- |
| Sand, loamy (upland mixed forest) | 2.8** | --- | --- | 1.2** | --- | --- |
| Sand, flatwoods (flatwoods forest) | 0.6** | 1.0** | 0.6** | -0.4** | -2.8** | --- |
| Sand, coastal (coastal hammock) | 4.2** | --- | --- | --- | --- | --- |
| Rockland, sandy (rockland hammock) | 0.0 | --- | --- | --- | --- | --- |
| Rockland, sandy (calcareous hammock[b]) | --- | --- | --- | 2.8** | --- | --- |

Table 125--Continued.

[a] Positive number indicates increase in spring diurnal surface temperature variation mean for urban/industrial cover type compared to that of the natural cover for the soil type.

[b] Represented by upland mixed forest.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Table 126. Winter diurnal surface temperature variation change from natural to urban/industrial in south zone.

| Soil type and natural cover | Difference in DSTV (C) mean for urban/industrial cover type[a] | | | | |
|---|---|---|---|---|---|
| | Suburb | Finger-canal suburb | Golf-course suburb | Indian reserv. | Urban center |
| Sand, flatwoods (flatwoods forest) | 1.6** | 1.0** | 1.0** | 2.0** | 1.2** |
| Sand, coastal (coastal hammock) | --- | 0.8** | --- | --- | --- |
| Rockland, sandy (rockland hammock) | --- | --- | -0.2 | --- | 0.4** |
| Rockland, marly (rockland hammock) | 1.8** | --- | --- | --- | --- |
| Organic, muck (marsh) | --- | --- | --- | --- | 2.6** |

[a] Positive number indicates increase in spring diurnal surface temperature variation mean for urban/industrial cover type compared to that of the natural cover for the soil type.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

counterparts are given in Table 127. The general trends were similar to those observed in spring.

<u>Zone N.</u> Differences in mean DSTV between zone N urban/ industrial cover/soil type combinations and their agricultural counterparts are given in Table 128. Many of the trends observed in spring were reduced in magnitude.

<u>Zone S.</u> Differences in mean DSTV between zone S urban/ industrial cover/soil type combinations and their agricultural counterparts are given in Table 129. Many of the trends observed in spring were reduced in magnitude. Some of the trends observed in spring were reversed for comparisons involving flatwoods sand soil type. This can be attributed to seasonal differences in agricultural irrigation practices.

<u>Winter Diurnal Comparison of Agricultural to Natural Extreme Islands</u>

<u>Zone P.</u> Differences in mean DSTV between agricultural cover types and the highest-DSTV natural feature of zone P (mixed scrub) are given in Table 130. Within zone P in winter, no agricultural combinations had DSTV matching that of the highest-DSTV natural feature.

<u>Zone N.</u> Differences in mean DSTV between agricultural cover types and the highest-DSTV natural feature of zone N (mixed scrub) are given in Table 130. Mixed agriculture (on deep sand, upland loamy sand, and sandy rockland) and citrus orchard on upland loamy sand had higher DSTV than did mixed scrub. There was no substantial difference between mixed

Table 127. Winter diurnal surface temperature variation change from agricultural to urban/industrial in panhandle zone.

| Soil type and agric. cover | Difference in DSTV (C) mean for urban/industrial cover type[a] Urban center |
|---|---|
| Sand, deep (mixed agric.) | -0.8** |
| Sand, loamy (mixed agric.) | -0.6** |
| Sand, flatwoods (pasture/ range) | -1.4** |

[a] Positive number indicates increase in spring diurnal surface temperature variation mean for urban/industrial cover type compared to that of the agricultural cover for the soil type.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Table 128. Winter diurnal surface temperature variation change from agricultural to urban/industrial in north zone.

| Soil type and agric. cover | Difference in DSTV (C) mean for urban/industrial cover type[a] | | | | | |
|---|---|---|---|---|---|---|
| | Suburb | Platted suburb | Golf-course suburb | Urban center | Phos. mine | Titan. mine |
| Sand, deep (citrus orchard) | 3.6** | --- | --- | -0.2 | --- | 0.2 |
| Sand, deep (mixed agric.) | -0.2 | --- | --- | -3.8** | --- | -3.6** |
| Sand, loamy (citrus orchard) | 0.8** | --- | --- | -0.8** | --- | --- |
| Sand, loamy (mixed agric.) | 0.2 | --- | --- | -1.4** | --- | --- |
| Sand, flatwoods (pasture/ range) | -0.8** | -0.4* | -0.8** | -1.8** | -4.2** | --- |
| Sand, flatwoods (citrus orchard) | -1.2** | -0.8** | -1.2** | -2.2** | -4.6** | --- |
| Sand, flatwoods (mixed agric.) | 1.0** | 1.6** | 1.2** | 0.2 | -2.2** | --- |
| Rockland, sandy (mixed agric.) | --- | --- | --- | 0.0 | --- | --- |

Table 128--Continued.

[a] Positive number indicates increase in spring diurnal surface temperature variation mean for urban/industrial cover type compared to that of the agricultural cover for the soil type.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Table 129. Winter diurnal surface temperature variation change from agricultural to urban/industrial in south zone.

| | Difference in DSTV (C) mean for urban/industrial cover type[a] | | | | |
|---|---|---|---|---|---|
| Soil type | Suburb | Finger-canal suburb | Golf-course suburb | Indian reserv. | Urban center |
| Sand, flatwoods (row-crops) | 1.8** | 1.2** | 1.2** | 2.2** | 1.4** |
| Sand, flatwoods (pasture/range) | -0.6** | -1.2** | -1.0** | 0.0 | -0.8** |
| Sand, flatwoods (citrus orchard) | 1.2** | 0.8** | 0.8** | 1.8** | 1.0** |
| Sand, flatwoods (mixed agric.) | -0.2** | -0.8** | -0.8** | 0.2** | -0.6** |
| Sand, coastal (row-crops) | --- | -0.4 | --- | --- | --- |
| Rockland, sandy (pasture/range) | --- | --- | -0.2* | --- | 0.2** |
| Rockland, sandy (mixed agric.) | --- | --- | -0.8** | --- | -0.2** |
| Rockland, marly (row-crops) | 1.2** | --- | --- | --- | --- |
| Rockland, marly (mixed agric.) | 0.4 | --- | --- | --- | --- |
| Organic, muck (pasture/sod) | --- | --- | --- | --- | 0.4* |
| Organic, muck (mixed agric.) | --- | --- | --- | --- | -2.0** |

[a] Positive number indicates increase in spring diurnal surface temperature variation mean for urban/industrial cover type compared to that of the agricultural cover for the soil type.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Table 130. Winter diurnal surface temperature variation of agricultural land-cover types vs highest-DSTV natural land-cover.

| Soil type | Difference in DSTV (C) mean for agricultural cover type[a] | | | | |
|---|---|---|---|---|---|
| | Row-crops | Pasture/ range | Pasture/ sod | Citrus orchard | Mixed |
| Zone P | | | | | |
| Sand, deep | --- | --- | --- | --- | -1.8** |
| Sand, loamy | --- | --- | --- | --- | -2.8** |
| Sand, flatwoods | --- | -3.0** | --- | --- | --- |
| Zone N | | | | | |
| Sand, deep | --- | --- | --- | -1.2** | 2.4** |
| Sand, loamy | --- | --- | --- | 1.2** | 2.0** |
| Sand, flatwoods | --- | 0.0 | --- | 0.4** | -2.0** |
| Rockland, sandy | --- | --- | --- | --- | 2.2** |
| Organic, muck | -0.4 | --- | 0.2 | --- | --- |
| Zone S | | | | | |
| Sand, deep | --- | --- | --- | -0.4* | --- |
| Sand, flatwoods | -2.6** | -0.4* | --- | -2.2** | -0.6** |
| Sand, coastal | -3.6** | --- | --- | --- | --- |
| Rockland, sandy | --- | -1.8** | --- | --- | -1.4** |
| Rockland, marly | -1.4** | --- | --- | --- | -0.4* |
| Organic, muck | --- | --- | -3.4** | --- | -1.0** |

[a] Positive number indicates increase in spring diurnal surface temperature variation mean for agricultural cover type compared to that of highest-DSTV natural cover type (mixed scrub in zones P and N, evergreen scrub in zone S).

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

scrub and row-crops and muck, pasture/range on flatwoods sand, pasture/sod on muck, citrus orchard on flatwoods sand. Other agricultural combinations had lower DSTV than did mixed scrub. In zone N in winter, several agricultural combinations had DSTV matching that of the highest-DSTV natural feature, and some had DSTV substantially exceeding it.

Zone S. Differences in mean DSTV between agricultural cover types and the highest-DSTV natural feature of zone S (evergreen scrub) are given in Table 130. There was no substantial difference in DSTV between evergreen scrub and pasture/range on flatwoods sand, citrus orchard on deep sand, and mixed agriculture (on flatwoods sand and marly rockland). Other agricultural combinations had lower DSTV than did evergreen scrub. In zone S in winter, several agricultural combinations had DSTV matching that of the highest-DSTV natural feature.

## Winter Diurnal Comparison of Urban/Industrial to Natural Extreme Islands

Zone P. Differences in mean DSTV between urban/industrial cover types and the highest-DSTV natural feature of zone P (mixed scrub) are given in Table 131. Within zone P in winter, no urban/industrial combinations had DSTV matching that of the highest-DSTV natural feature.

Zone N. Differences in mean DSTV between urban/industrial cover types and the highest-DSTV natural feature of zone N (mixed scrub) are given in Table 131. Normal suburb on

Table 131. Winter diurnal surface temperature variation of urban/industrial land-cover types vs highest-DSTV natural land-cover.

| Soil type | Difference in DSTV (C) mean for urban/industrial cover type[a] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Suburb | Platted suburb | Finger-canal suburb | Golf-course suburb | Indian reserv. | Urban center | Phos. mine | Tita. mine |
| Zone P | | | | | | | | |
| Sand, deep | --- | --- | --- | --- | --- | $-2.6^{**}$ | --- | --- |
| Sand, loamy | --- | --- | --- | --- | --- | $-3.4^{**}$ | --- | --- |
| Sand, flatwoods | --- | --- | --- | --- | --- | $-4.4^{**}$ | --- | --- |
| Sand, coastal | $-5.0^{**}$ | --- | --- | --- | --- | $-7.0^{**}$ | --- | --- |
| Zone N | | | | | | | | |
| Sand, deep | $2.4^{**}$ | --- | --- | --- | --- | $-1.4^{**}$ | --- | $-1.0^{**}$ |
| Sand, loamy | $2.0^{**}$ | --- | --- | --- | --- | $0.4^{**}$ | --- | --- |
| Sand, flatwoods | $-1.0^{**}$ | $-0.4^{*}$ | --- | $-0.8^{**}$ | --- | $-1.8^{**}$ | $-4.2^{**}$ | --- |
| Sand, coastal | -0.2 | --- | --- | --- | --- | --- | --- | --- |
| Rockland, sandy | $-1.2^{**}$ | --- | --- | --- | --- | $2.2^{**}$ | --- | --- |

Table 131--Continued.

| | Difference in DSTV (C) mean for urban/industrial cover type[a] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Soil type | Suburb | Platted suburb | Finger-canal suburb | Golf-course suburb | Indian reserv. | Urban center | Phos. mine | Tita. mine |
| Zone S | | | | | | | | |
| Sand, flatwoods | -1.0** | --- | -1.6** | -1.4** | -0.4* | -1.2** | --- | --- |
| Sand, coastal | --- | --- | -4.0** | --- | --- | --- | --- | --- |
| Rockland, sandy | --- | --- | --- | -2.2** | --- | -1.6** | --- | --- |
| Rockland, marly | -0.2 | --- | --- | --- | --- | --- | --- | --- |
| Organic, muck | --- | --- | --- | --- | --- | -3.0** | --- | --- |

[a] Positive number indicates increase in spring diurnal surface temperature variation mean for urban/industrial cover type compared to that of highest-DSTV natural cover type (mixed scrub in zones P and N, evergreen scrub in zone S).

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

deep sand and on upland loamy sand had higher DSTV (by up to 2.4 C) than did mixed scrub. There was no substantial difference between mixed scrub and suburb on coastal sand, platted suburb on flatwoods sand, golf-course suburb on flatwoods sand, and urban center on upland loamy sand. In zone N in winter, several urban/industrial cover types had DSTV matching that of the highest-DSTV natural feature, but only suburb (on deep sand and upland loamy sand) had DSTV exceeding it.

Zone S. Differences in mean DSTV between urban/ industrial cover types and the highest-DSTV natural feature of zone S (evergreen scrub) are given in Table 131. There was no substantial difference in DSTV between evergreen scrub and suburb on marly rockland or Indian reservation on flatwoods sand. In zone S in winter, two urban/industrial combinations had DSTV matching that of the highest-DSTV natural feature.

## Winter Diurnal Change Analyses--Special Factors

Natural factors. Normal and droughty natural land-cover types were compared. As shown in Table 132, droughty bay swamp (mean 14.0 C) had higher DSTV (by 2.0 C) than did normal bay swamp. The difference in DSTV between droughty mixed swamp (mean 13.6 C) and normal mixed swamp was significant, but not substantial. The greater drought-related increase in DSTV for bay swamp than for mixed swamp can be attributed to the organic soil of bay swamp.

Table 132. Winter diurnal surface temperature variation change for special conditions.

| Zone | Difference in DSTV (C) mean for cover type under special condition[a] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Bay swamp[b] | Mixed swamp[c] | Citrus orchard[d] | Urban center[e] | Cypress swamp[f] | Marsh[g] | Marsh[h] | Flatwoods forest[i] |
| N | 2.0** | 0.8** | 2.8** | --- | --- | --- | --- | --- |
| S | --- | --- | --- | 0.2 | 3.8** | 2.2** | 0.0 | 0.0 |

[a] Positive number indicates increase in spring diurnal surface temperature variation mean for cover type under special condition compared to that of the cover type under normal condition.

[b] Bay swamps under drought condition in north-central Florida (Sandlin Bay and Little Santa Fe Lake area) compared to those under normal condition in central Florida (Chassahowitzka Swamp). See also Mixed Swamp note below.

[c] Mixed swamps under drought condition in north-central Florida and south Georgia (Okeefenokee N.W.R. south of Suwannee R., Pinhook Swamp) compared to those under normal condition in other areas (Okeefenokee N.W.R., north of Suwannee R., Withlacoochee State Forest southeast, Devils Hammock, Hull Cypress Swamp/Bennett Swamp, Spruce Creek Swamp, and Wekiva Swamp). The Okeefenokee N.W.R. hydrology is controlled by a system of dikes and canals along the Suwannee R. Wildfire broke out in the drought-stricken mixed swamp area six months (June 1993) after this image (Dec. 1992).

[d] Citrus orchard (on deep sand) in area heavily damaged by freezes of mid 1980s (Okahumpka/Clermont area) compared to citrus orchard (on deep sand) in areas which had quickly recovered (Ft. Meade, east area and Lake Wales area).

[e] Urban center on sandy rockland, heavily damaged in 1993, but under normal condition in this 1989 image, compared to urban center on sandy rockland under normal condition in both 1989 and 1993.

Table 132--Continued.

[f] Disturbed dwarf-cypress swamp in abandoned platted subdivision (Golden Gate Estates, east area) compared to normal dwarf-cypress swamps nearby (Big Cypress National Preserve--central, southeast, and southwest).

[g] Marsh within the EAA canal system (Holey Land/Rotenberger Wildlife Management Areas) compared to marsh in less-impacted areas (Moonshine Bay area of Lake Okeechobee, Water Conservation Area 2, and Little Doctor Village/Custard Apple Hammock area of the deep Everglades).

[h] Marsh within an area heavily impacted by EAA drainage system (Water Conservation Area 1) compared to marsh in less-impacted areas (Moonshine Bay area of Lake Okeechobee, Water Conservation Area 2, and Little Doctor Village/Custard Apple Hammock area of the deep Everglades).

[i] Flatwoods forest (on flatwoods sand) in West Green Acres area invaded by exotic forest, compared to normal flatwoods forest in other areas (Gator Slough, C. M. Webb WMA, J. W. Corbett WMA, Keri area, and Rainey Slough).

[*] Significant at $\alpha = 0.05$.

[**] Significant at $\alpha = 0.01$.

Freeze-damaged and normal citrus orchard land-cover were compared. As shown on Table 132, freeze-damaged citrus orchard on deep sand (mean 16.0 C) had higher DSTV (by 2.8 C) than did normal citrus orchard on deep sand. This increase in DSTV for the damaged area may be attributed to the loss of tree canopy on abandoned groves, and to decreased canopy on groves converted to pine plantations (very young at image date) and vineyards.

A check on the pre-hurricane (1989) similarity of the Homestead urban center and normal urban center on sandy rockland was performed. As shown in Table 132, there was no substantial difference in DSTV between the pre-hurricane Homestead urban center on sandy rockland (mean 7.6 C) and the normal urban center on sandy rockland. This indicates the validity of comparing the two sites under post-hurricane condition.

<u>Artificial factors.</u> Disturbed and normal dwarf-cypress land-cover types were compared. As shown in Table 132, disturbed dwarf cypress swamp (mean 9.8 C) had higher DSTV (by 3.8 C) than did normal dwarf cypress swamp.

Disturbed and normal marsh land-cover types were compared. As shown in Table 132, marsh within the Holey Land/Rotenburger Wildlife Management Area of the EAA (mean 5.8 C) had higher DSTV (by 2.2 C) than did normal marsh. As shown in Table 132, there was no significant difference in DSTV between marsh within the Water Conservation Area 1 (mean

3.6 C) and normal marsh; this may be due to water-storage in WCA-1 for the coming spring dry-season.

Exotic forest and normal flatwoods forest land-cover types were compared. As shown in Table 132, there was no significant difference in DSTV between exotic forest (mean 6.4 C) had higher DSTV (by 3.4 C) and normal flatwoods forest. These findings for disturbed wetlands and exotic-invaded flatwoods forest indicate that major disturbances (widespread change in vegetation species composition accompanied by/related to major hydrologic alteration) of natural communities, can lead to increased DSTV.

## Analyses of Micro-Scale Maritime Effects

The micro-scale maritime effect was studied through analyses of thermal pattern differences between interior and coastal examples of similar natural land-cover type. These included rockland hammock paired with coastal hammock, and marsh paired with saltmarsh. Hammock comparisons were limited to zones N and S (rockland hammock was not present in zone P), and marsh comparisons were limited to zones P and N (comparisons of zone S brackish marsh with marsh would have included the confounding effect of seasonal fluctuation in soil moisture for the brackish marsh).

### Hammock Comparisons

Spring season. In spring in zone N, rockland hammock had higher DSTV (by 1.0 C) (Table 50) than did coastal hammock.

There were no substantial differences in AST (Table 8) or NST (Table 29). In spring in zone S, rockland hammock had higher AST (by 3.2 C) (Table 9), lower NST (by 3.0 C) (Table 30), and higher DSTV (by 6.0 C) (Table 51) than did coastal hammock.

Winter season. In winter in zone N, rockland hammock had lower NST (by 3.2 C) (Table 92) and higher DSTV (by 3.0 C) (Table 113) than did coastal hammock. There was no substantial difference in AST (Table 71). In winter in zone S, rockland hammock had lower NST (by 2.0 C) (Table 93) and higher DSTV (by 2.8 C) (Table 114) than did coastal hammock. There was no substantial difference in AST (Table 72).

## Marsh Comparisons

Spring season. In spring in zone P, marsh had higher AST (by 2.8 C) (Table 7) and higher DSTV (by 3.4 C) (Table 49) than did saltmarsh. There was no substantial difference in NST (Table 28). In spring in zone N, marsh had higher AST (by 2.8 C) (Table 8), lower NST (by 1.2 C) (Table 29), and higher DSTV (by 4.0 C) (Table 50) than did saltmarsh.

Winter season. In winter in zone P, marsh had lower NST (by 2.2 C) and higher DSTV (by 2.4 C) than did saltmarsh. There was no substantial difference in AST. In winter in zone N, marsh had higher AST (by 1.4 C) and higher DSTV (by 1.8 C) than did saltmarsh. There was no substantial difference in NST (Table 92).

## Maritime Micro-Scale Thermal Moderation

The above analyses indicated a thermal-pattern moderating effect for the micro-scale (immediately adjacent to the coast) advective component of the maritime influence. This moderating effect amounted to a decrease in AST of up to 3.2 C, an increase in NST of up to 3.2 C, and a decrease in DSTV of up to 6.0 C.

## Analyses of Seasonal Effects on Deciduous Vegetation

The evergreen and mixed (partly deciduous) subtypes of scrub were chosen for analyses of the seasonal thermal effects of defoliation. Other pairs of evergreen and deciduous natural land-cover subtypes also exist (hardwood swamp, shrubby marsh), but their analyses would have been confounded by differences in soil moisture. In winter in zone N, mixed scrub had higher AST (by 1.2 C) (Table 71) than did evergreen scrub; there were no substantial differences in NST (Table 92) or DSTV (Table 113) between the two scrub subtypes. The higher AST for mixed scrub in winter can be attributed to the greater fraction of exposed soil. In spring in zone N, there were no substantial differences in AST (Table 8), NST (Table 29), or DSTV (Table 50) between mixed scrub and evergreen scrub (deciduous trees fully foliated).

## Historical HCMM-Based Analyses

The results for the historical HCMM-based analyses are presented below. It should be remembered that the HCMM images were processed to at-satellite radiant temperature, rather than surface (kinetic) temperature. For reasons described in the section concerning HCMM image processing, these HCMM images were not corrected for atmospheric or emissivity effects. Because of the extraneous effects on radiant temperature values produced by differences in surface emissivity, comparisons of HCMM data were made only between land-cover types having near-identical surfaces.

### HCMM Analyses Across Macroclimate Zones

Across-zone analyses were performed for the two most different natural land-cover types (scrub and marsh) to assess the macroclimate component of across-zone bias. Results are shown in Tables 133, 134, and 135 respectively for AST, NST, and approximate-DSTV of winter 1979. Macroclimate influence produced substantial differences in these three surface temperature patterns between macroclimate zones N and S (zone P was not present in the HCMM images) for evergreen scrub and marsh.

The AST and NST values were generally higher with distance south in both spring and winter, as expected. AST across-zone differences ranged to 6.2 C, while NST across-zone differences ranged to 6.6 C. The DSTV across-zone differences

Table 133. HCMM winter approximate afternoon surface temperature across-zone differences among natural land-cover types.

| Natural cover type | Zones crossed | | | Difference in AST means (C)[a] |
|---|---|---|---|---|
| Scrub, evergreen | N | to | S | 6.2** |
| Marsh | N | to | S | 2.6** |

[a] difference is positive if mean of zone at right is larger than mean of zone at left.

* significant at $\alpha = 0.05$.

** significant at $\alpha = 0.01$.

Table 134. HCMM winter approximate nighttime surface temperature across-zone differences among natural land-cover types.

| Natural cover type | Zones crossed | Difference in NST means (C)[a] |
|---|---|---|
| Scrub, evergreen | N to S | 2.6** |
| Marsh | N to S | 6.6** |

[a] difference is positive if mean of zone at right is larger than mean of zone at left.

* significant at $\alpha = 0.05$.

** significant at $\alpha = 0.01$.

Table 135. HCMM winter approximate diurnal surface temperature variation across-zone differences among natural land-cover types.

| Natural cover type | Zones crossed | | | Difference in DSTV means (C)[a] |
|---|---|---|---|---|
| Scrub, evergreen | N | to | S | 3.6** |
| Marsh | N | to | S | -4.0** |

[a] difference is positive if mean of zone at right is larger than mean of zone at left.

* significant at $\alpha = 0.05$.

** significant at $\alpha = 0.01$.

were less easy to predict, since they serve as an indication of differences in relative moisture conditions for a given natural land-cover from zone to zone. DSTV across-zone differences ranged to 3.6 C for the evergreen scrub, but ranged to -4.0 C for marsh. These results indicate that any comparisons of surface temperature pattern differences across macroclimate zones would have to be made with due consideration of the macroclimate component of zone bias.

## HCMM Historical Special Condition Change Analyses

Within-zone analyses were performed to assess the surface temperature effects of special conditions and some pre-event (1979) conditions. Cloud-contamination of portions of the HCMM images prevented the study of some special land-cover conditions. Results are discussed below.

HCMM afternoon change analyses--natural factors. Normal and pre-drought natural land-cover types were compared. As shown in Table 136, pre-drought bay swamp actually had lower AST (by 3.0 C) than did normal bay swamp. This indicates that the pre-drought bay swamp was just as wet as, and probably wetter than, the "normal" bay swamp in 1979.

Normal and pre-freeze citrus orchard land-cover were compared. As shown on Table 136, pre-freeze citrus orchard on deep sand actually had lower AST (by 2.2 C) than did normal citrus orchard on deep sand. This indicates that the pre-freeze citrus orchard was probably in just as vigorous

Table 136. HCMM winter approximate afternoon surface temperature change for special conditions.

| | Difference in AST (C) mean for cover type under special condition[a] | | | | | |
|---|---|---|---|---|---|---|
| Zone | Bay swamp[b] | Citrus orchard[c] | Urban center[d] | Cypress swamp[e] | Marsh[f] | Marsh[g] |
| N | -3.0** | -2.2** | --- | --- | --- | --- |
| S | --- | --- | -0.8** | 3.2** | 1.8** | 0.2** |

[a] Positive number indicates increase in spring afternoon surface temperature mean for cover type under special condition compared to that of the cover type under normal condition.

[b] Bay swamps (under drought condition in north-central Florida in 1993, but under normal condition in this 1979 image) compared to other bay swamps in central Florida (under normal conditions in 1979 and 1993).

[c] Citrus orchard on deep sand (heavily damaged by freezes on 1993 images, but under normal condition in this 1979 image) compared to other citrus orchards on deep sand (under normal conditions in 1979 and 1993).

[d] Urban center (Homestead/Leisure City area) on sandy rockland (damaged by hurricane in 1993 image, but under normal condition in this 1979 image), compared to other urban center on sandy rockland (under normal condition in 1979 and 1993).

[e] Dwarf-cypress swamp under disturbed condition (both in 1993 and in this 1979 image) compared to other dwarf-cypress swamps nearby (under normal condition in 1979 and 1993).

[f] Marsh within the EAA canal system (both in 1993 and in this 1979 image) compared to other marsh (under normal condition in 1979 and 1993).

[g] Marsh within an area impacted by EAA drainage system both in 1993 and in this 1979 image (Water Conservation Area 1) compared to other marsh (under normal condition in 1979 and 1993).

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

condition as, if not somewhat more vigorous than, the "normal" citrus orchard further south in 1979.

A check on the pre-hurricane (1979) similarity of the Homestead urban center and normal urban center on sandy rockland was performed. As shown in Table 136, there was no substantial difference in AST between the pre-hurricane Homestead urban center on sandy rockland and the normal urban center on sandy rockland. This indicates the validity of comparing the two sites under post-hurricane condition.

<u>HCMM afternoon change analyses--artificial factors</u>. Disturbed and normal dwarf-cypress land-cover types were compared (this distinction existed even earlier than 1979). As shown in Table 136, disturbed dwarf cypress swamp had higher AST (by 3.2 C) than did normal dwarf cypress swamp.

Disturbed and normal marsh land-cover types were compared (this distinction existed even earlier than 1979). As shown in Table 136, marsh within the Holey Land/Rotenburger Wildlife Management Area of the EAA had higher AST (by 1.8 C) than did normal marsh. As shown in Table 136, there was no substantial difference in AST between marsh within the Water Conservation Area 1 and normal marsh; this may be due to water-storage in WCA-1 for the coming spring dry-season. These findings for disturbed wetlands indicate that major disturbances (widespread change in vegetation species composition accompanied by/related to major hydrologic alteration) of natural communities can lead to increased AST.

<u>HCMM nighttime change analyses--natural factors</u>. Normal and pre-drought natural land-cover types were compared. As shown in Table 137, pre-drought bay swamp had lower NST (by 1.8 C) than did normal bay swamp. Since the pre-drought bay swamp was shown to be no drier than normal bay swamp by the DSTV (discussed later), this may simply indicate the level of noise in the at-satellite radiant temperature data even for near-identical surfaces.

Normal and pre-freeze citrus orchard land-cover were compared. As shown on Table 137, there was no substantial difference in NST between pre-freeze citrus orchard on deep sand and normal citrus orchard on deep sand. This indicates that the pre-freeze citrus orchard was probably in just as vigorous condition as the "normal" citrus orchard further south in 1979.

A check on the pre-hurricane (1979) similarity of the Homestead urban center and normal urban center on sandy rockland was performed. As shown in Table 137, there was no substantial difference in NST between the pre-hurricane Homestead urban center on sandy rockland and the normal urban center on sandy rockland. This indicates the validity of comparing the two sites under post-hurricane condition.

<u>HCMM nighttime change analyses--artificial factors</u>. Disturbed and normal dwarf-cypress land-cover types were compared (this distinction existed even earlier than 1979). As shown in Table 137, disturbed dwarf cypress swamp had lower NST (by 4.0 C) than did normal dwarf cypress swamp.

Table 137. HCMM winter approximate nighttime surface temperature change for special conditions.

| | Difference in NST (C) mean for cover type under special condition[a] | | | | | |
|---|---|---|---|---|---|---|
| Zone | Bay swamp[b] | Citrus orchard[c] | Urban center[d] | Cypress swamp[e] | Marsh[f] | Marsh[g] |
| N | -1.8** | -0.6** | --- | --- | --- | --- |
| S | --- | --- | -0.4** | -4.0** | -4.4** | -0.4** |

[a] Positive number indicates increase in spring afternoon surface temperature mean for cover type under special condition compared to that of the cover type under normal condition.

[b] Bay swamps (under drought condition in north-central Florida in 1993, but under normal condition in this 1979 image) compared to other bay swamps in central Florida (under normal conditions in 1979 and 1993).

[c] Citrus orchard on deep sand (heavily damaged by freezes on 1993 images, but under normal condition in this 1979 image) compared to other citrus orchards on deep sand (under normal conditions in 1979 and 1993).

[d] Urban center (Homestead/Leisure City area) on sandy rockland (damaged by hurricane in 1993 image, but under normal condition in this 1979 image), compared to other urban center on sandy rockland (under normal condition in 1979 and 1993).

[e] Dwarf-cypress swamp under disturbed condition (both in 1993 and in this 1979 image) compared to other dwarf-cypress swamps nearby (under normal condition in 1979 and 1993).

[f] Marsh within the EAA canal system (both in 1993 and in this 1979 image) compared to other marsh (under normal condition in 1979 and 1993).

[g] Marsh within an area impacted by EAA drainage system both in 1993 and in this 1979 image (Water Conservation Area 1) compared to other marsh (under normal condition in 1979 and 1993).

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

Disturbed and normal marsh land-cover types were compared (this distinction existed even earlier than 1979). As shown in Table 137, marsh within the Holey Land/Rotenburger Wildlife Management Area of the EAA had lower NST (by 4.4 C) than did normal marsh. As shown in Table 137, there was no substantial difference in NST between marsh within the Water Conservation Area 1 and normal marsh; this may be due to water-storage in WCA-1 for the coming spring dry-season. These findings for disturbed wetlands indicate that major disturbances (widespread change in vegetation species composition accompanied by/related to major hydrologic alteration) of natural communities appear to decrease NST.

HCMM diurnal change analyses--natural factors. Normal and pre-drought natural land-cover types were compared. As shown in Table 138, pre-drought bay swamp had lower DSTV (by 1.2 C) than did normal bay swamp. This indicates that the pre-drought bay swamp was just as wet as, and probably wetter than, the "normal" bay swamp in 1979.

Normal and pre-freeze citrus orchard land-cover were compared. As shown on Table 138, pre-freeze citrus orchard on deep sand actually had lower DSTV (by 1.4 C) than did normal citrus orchard on deep sand. This indicates that the pre-freeze citrus orchard was probably in just as vigorous condition as, if not somewhat more vigorous than, the "normal" citrus orchard further south in 1979.

A check on the pre-hurricane (1979) similarity of the Homestead urban center and normal urban center on sandy

Table 138. HCMM winter approximate diurnal surface temperature variation change for special conditions.

| | Difference in DSTV (C) mean for cover type under special condition[a] | | | | | |
|---|---|---|---|---|---|---|
| Zone | Bay swamp[b] | Citrus orchard[c] | Urban center[d] | Cypress swamp[e] | Marsh[f] | Marsh[g] |
| N | -1.2** | -1.4** | --- | --- | --- | --- |
| S | --- | --- | -0.4 | 7.2** | 6.2** | 0.6** |

[a] Positive number indicates increase in spring afternoon surface temperature mean for cover type under special condition compared to that of the cover type under normal condition.

[b] Bay swamps (under drought condition in north-central Florida in 1993, but under normal condition in this 1979 image) compared to other bay swamps in central Florida (under normal conditions in 1979 and 1993).

[c] Citrus orchard on deep sand (heavily damaged by freezes on 1993 images, but under normal condition in this 1979 image) compared to other citrus orchards on deep sand (under normal conditions in 1979 and 1993).

[d] Urban center (Homestead/Leisure City area) on sandy rockland (damaged by hurricane in 1993 image, but under normal condition in this 1979 image), compared to other urban center on sandy rockland (under normal condition in 1979 and 1993).

[e] Dwarf-cypress swamp under disturbed condition (both in 1993 and in this 1979 image) compared to other dwarf-cypress swamps nearby (under normal condition in 1979 and 1993).

[f] Marsh within the EAA canal system (both in 1993 and in this 1979 image) compared to other marsh (under normal condition in 1979 and 1993).

[g] Marsh within an area impacted by EAA drainage system both in 1993 and in this 1979 image (Water Conservation Area 1) compared to other marsh (under normal condition in 1979 and 1993).

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

rockland was performed. As shown in Table 138, there was no substantial difference in DSTV between the pre-hurricane Homestead urban center on sandy rockland and the normal urban center on sandy rockland. This indicates the validity of comparing the two sites under post-hurricane condition.

HCMM diurnal change analyses--artificial factors. Disturbed and normal dwarf-cypress land-cover types were compared (this distinction existed even earlier than 1979). As shown in Table 138, disturbed dwarf cypress swamp had higher DSTV (by 7.2 C) than did normal dwarf cypress swamp.

Disturbed and normal marsh land-cover types were compared (this distinction existed even earlier than 1979). As shown in Table 138, marsh within the Holey Land/Rotenburger Wildlife Management Area of the EAA had higher DSTV (by 6.2 C) than did normal marsh. As shown in Table 138, there was no substantial difference in DSTV between marsh within the Water Conservation Area 1 and normal marsh; this may simply indicate the effects of water-storage in WCA-1 for the coming spring dry-season. These findings for disturbed wetlands indicate that major disturbances (widespread change in vegetation species composition accompanied by/related to major hydrologic alteration) of natural communities can lead to increased DSTV.

## Results of Ground-Based DSTV/Soil-Moisture

The results of the ground-based investigations of the effects of soil type and vegetation on the DSTV/soil-moisture

relation were quite positive. They are presented for mineral soil, organic soil, and vegetated soil in Table 139.

## Mineral Soil Results

For the case of the mineral soil, DSTV was strongly and inversely correlated with gravimetric soil moisture, not just in the surface layer (1d = 8 cm), but to the entire depth studied (40 cm). The linear regression of the relation in the 1d depth was of the form:

$$DSTV = -0.0167\ GSM_{1d} + 0.431,\ (r^2 = 0.99) \qquad [30]$$

where DSTV is the diurnal surface temperature variation (K) determined from the average temperature recorded by three thermistor probes in morning and in afternoon, and $GSM_{1d}$ is the daily-average gravimetric soil moisture (unitless) for the 0 to 8 cm soil depth. This inverse relation was predicted by equation 5. The linear regression of the relation in the 3d depth was of the form:

$$DSTV = -0.0125\ GSM_{3d} + 0.362,\ (r^2 = 0.98) \qquad [31]$$

where DSTV is defined as before, and $GSM_{3d}$ is the daily-average gravimetric soil moisture (unitless) for the 0 to 24 cm soil depth.

Table 139. DSTV/soil-moisture relation for soil types.

| Soil type[1] | Correlation ($r^2$) of DSTV with soil moisture in depth[2] | | | | | |
|---|---|---|---|---|---|---|
| | 1d | 2d | 3d | 4d | 5d | 6d |
| Mineral | 0.99 | 0.98 | 0.99 | 0.98 | 0.98 | ---- |
| Organic | 0.80 | 0.81 | 0.69 | 0.57 | 0.43 | 0.36 |
| Vegetated | 0.80 | 0.65 | 0.77 | 0.78 | 0.68 | 0.51 |

[1] Mineral soil = Ellzey fine sand (north Florida); organic soil = Pahokee muck (south Florida); vegetated soil = Blichton sand with cover of pasture grasses (north Florida).

[2] DSTV = diurnal surface temperature variation (K); normalized (with diurnal air-temperature variation) for the cases of organic soil (to remove effects of variation in transpiration of nearby vegetation) and vegetated mineral soil (to remove effects of variation in grass transpiration). Soil moisture was by gravimetric analysis. The value of d was 8 cm for the mineral and vegetated mineral soils, and 3 cm for the organic soil.

## Organic Soil Results

For the case of the organic soil, $DSTV_n$ was strongly and inversely correlated with gravimetric soil moisture, not just in the surface layer (1d = 3 cm), but to a depth of 2d = 6 cm. The linear regression of the relation in the 1d depth was of the form:

$$DSTV_n = -0.546\ GSM_{1d} + 57.1,\ (r^2 = 0.80) \qquad [32]$$

where $DSTV_n$ is the normalized diurnal surface temperature variation (K) determined from the average temperature recorded by three thermistor probes in morning and in afternoon, and $GSM_{1d}$ is the daily-average gravimetric soil moisture (unitless) for the 0 to 3 cm soil depth. This inverse relation was predicted by equation 5; the decrease in correlation results with depth was predicted by equation 2. The linear regression of the relation in the 3d depth was of the form:

$$DSTV_n = -0.393\ GSM_{3d} + 47.7,\ (r^2 = 0.69) \qquad [33]$$

where $DSTV_n$ is defined as before, and $GSM_{3d}$ is the daily-average gravimetric soil moisture (unitless) for the 0 to 9 cm soil depth.

## Vegetated Soil Results

For the case of the vegetated mineral soil, $DSTV_n$ was strongly and inversely correlated with gravimetric soil moisture in the surface layer (1d = 8 cm), but less so at

greater depths. The observed dip in correlation for the 2d depth can be attributed to the distribution of the grass roots--a network of feeder roots in the surface layer (1d) and water-tapping roots in the deeper layers (3d to 5d). The linear regression of the relation in the 1d depth was of the form:

$$DSTV_n = -26.1\ GSM_{1d} + 3.29,\ (r^2 = 0.80) \qquad [34]$$

where $DSTV_n$ is the normalized diurnal surface temperature variation (K) determined from the average temperature recorded by three thermistor probes in morning and in afternoon, and $GSM_{1d}$ is the daily-average gravimetric soil moisture (unitless) for the 0 to 8 cm soil depth. This inverse relation was expected. The linear regression of the relation in the 3d depth was of the form:

$$DSTV_n = -29.3\ GSM_{3d} + 3.11,\ (r^2 = 0.77) \qquad [35]$$

where $DSTV_n$ is defined as before, and $GSM_{3d}$ is the daily-average gravimetric soil moisture (unitless) for the 0 to 24 cm soil depth.

## SUMMARY AND CONCLUSIONS

This study has demonstrated that a detailed, quantitative investigation of kilometer-resolution surface temperature patterns can be conducted through the use of remote sensing and GIS methodology. The AVHRR satellite images were shown to be capable, through careful correction of geographic distortion, atmospheric effects, and emissivity effects, of providing land surface temperature data of sufficient spatial and radiometric accuracy to distinguish (at high statistical significance) seasonal and diurnal patterns of many different combinations of land-cover and soil type. Distinction of surface temperature patterns was also demonstrated for the special conditions of natural origin (drought, freeze, hurricane) and those of artificial origin (hydrologic disturbance, exotic forest invasion).

In addition, the thermal patterns observed for Florida natural land-cover types in this study may serve as rough representations of those for similar natural land-cover types found elsewhere. Florida scrub shares the primary characteristics (xeric vegetation and seasonal rainfall distribution) of tropical scrub like that in India and parts of South America--but not of Mediterranean scrub (reversed seasonal rainfall pattern). Upland mixed forest and deciduous swamp are pan-temperate in distribution. Rockland hammock

similar to that in Florida is found in many tropical regions (Yucatan, Caribbean, Pacific atolls, etc.). Calcareous hammock occurs in other parts of North America, and in Europe. Evergreen swamp and mangrove swamp are pan-tropical in distribution. Marsh and saltmarsh are worldwide in distribution.

## Principal Findings

During the course of this research, several principal findings of general applicability to surface temperature work were made. These are discussed below.

### Importance of Soil Type and Land-Cover

Both soil type and land-cover were demonstrated to be important factors of the surface temperature pattern, together with macroclimate and root-zone soil moisture. This means that meso-scale studies involving surface temperature must take into account not only the land-cover, as has been conventional, but also the soil type. This is particularly important for analyses of surface temperature pattern change related to land-cover change. For example, it is valid to evaluate the impact of a given urban center on deep sand soil compared to that of natural or agricultural land-cover types on deep sand soil, but not to that of natural or agricultural land-cover types on flatwoods sand/loam/organic soil, even if these exist adjacent to the urban center.

Differences Among Natural Land-Cover Types

Substantial differences in the surface temperature patterns among the various types of natural land-cover were observed. Many of these differences were of similar magnitude to those reported for urban center heat-island effects in previous studies. In addition, there were seasonal effects which altered the thermal patterns of some natural land-cover types--seasonal soil moisture fluctuation for flatwoods forest and wet-prairie, and (to a lesser degree) seasonal defoliation of deciduous vegetation types. This means that studies of surface temperature patterns must take into account not just the general category of "natural" land-cover, as has been conventional, but the exact type of natural land-cover (and in some cases the season).

Differences Among Agricultural Land-Cover Types

Agricultural land-cover types were shown to have surface temperature impacts which in certain cases matched, or even exceeded, those of urban land-cover. This indicates the need for greater attention to be paid to agricultural land-cover in meso-scale climate studies. Substantial differences in the surface temperature patterns among the various types of agriculture were also observed. This means that studies of surface temperature patterns must take into account not just the general category of "agricultural" land-cover, as has been conventional, but the exact type of agriculture.

Differences Among Urban/Industrial Land-Cover Types

Substantial differences in the surface temperature patterns among the various types of urban/industrial land-cover were observed. This means that studies involving meso-scale surface temperature patterns must take into account not just the general category of "urban" or "suburban" land-cover, as has been conventional, but the exact type of urban/industrial land-cover. In addition, certain urban/industrial land-cover types had components which strongly influenced their overall surface temperature. These were found to include golf-course suburbs--whose nighttime irrigation increased their pixel-average nighttime surface temperature, as well as finger-canal suburbs and strip mines--whose inclusion of small water-bodies moderated their pixel-average surface temperature patterns. Similar situations may exist for urban/industrial land-cover subtypes in other regions.

Potential for Soil Moisture Monitoring

The DSTV/soil-moisture relation was observed to be quite strong for examples of mineral, organic, and vegetated (grass) soil in the ground-based portion of this study. This indicates the potential for operational applications such as the monitoring of organic soil conservation and naturalization efforts by the methodology of this study. For example, the exhibition of a combination of lower AST, higher NST, and lower DSTV over time could serve as an indication of wetter

surface hydrology for organic soil conservation or marsh restoration, more closed natural vegetation canopy due to reforestation/mined-land reclamation, or decreased percentage of exotic trees due to eradication. These topics are of particular concern in Florida, due to the vast areas of organic soil under agricultural use, and the vast areas of wetlands under direct hydrologic control.

## Recommendations for Future Research

Several recommendations can be made for future work involving meso-scale land surface temperature. These concern ground-based water-body temperature station networks, the TIROS satellite system, and the direction of future research.

### Ground-Based Data Collection Improvement

The network of water-body temperature measurement stations for Florida should be expanded. A larger network would allow zone by zone atmospheric correction of images, with a reserve of data for processed temperature verification. This might decrease the atmospheric component of across-zone surface temperature error to below 1 C.

Suitably large lakes and reservoirs for use with kilometer-resolution image data exist in all three macroclimate zones. Lake Istokpoga, Lake George, Crescent Lake, Lake Santa Fe, Newnans Lake, Parish Lake, Lake Kissimmee, Lake Monroe, Lake Washington, Lake Seminole, Lake Iamonia, and Lake Miccosukee could all serve as locations for

permanent stations. The periodic sampling available from Lake Sampson, Lake Tohopekaliga, and Lake Hatchineha could be upgraded with permanent stations. Sea-surface temperatures, now available periodically by boat measurements, could be upgraded by permanent stations at many points along the coast.

These permanent stations should take the form of towers, which are less susceptible to vandalism and animal (bird and alligator) disturbance than moored rafts. In addition, a real-time link between the image processing facility and the water-body stations would allow near real-time production of TIROS AVHRR-based surface temperature images. This would be useful for near real-time applications such as drought and freeze monitoring in agriculture and forestry, which have previously been performed with GOES VISSR-based at-satellite radiant temperature images (Waters, 1976; Chen, 1980; Chen et al., 1982). Such an expanded water-body station system could also be applied to other states and countries.

Satellite System Improvement

The TIROS satellite system, with its capabability of providing repeat coverage several times each day, and its AVHRR sensor with twin longwave thermal-infrared bands for emissivity mapping and red and near-infrared bands for vegetation index mapping, is already a very good tool for global kilometer-resolution research (in addition to its other duties in meteorology and atmospheric study). However, several improvements could be made to this public weather

satellite system to make its images as efficient for operational, meso-scale, land-surface temperature work as the proprietary observational satellite systems (Landsat, SPOT, IRS, etc.) currently are for micro-scale, land-cover classification work.

First, the number of full-resolution images available for research needs to be increased. This might be done by improving the onboard data recording system to allow a greater number of LAC images to be archived by NOAA, or by making available to the user community a software package for full processing (with research-quality radiometric calibration and ELP calculation) of HRPT format AVHRR images.

Second, the thermal-infrared sensor could be improved with a higher saturation limit. This would be of great interest for land surface temperature research in desert regions, where a strong likelihood of daytime AVHRR thermal-infrared sensor saturation currently exists.

Third, a sensor with a pair of narrower and spectrally closer longwave thermal-infrared bands would result in more accurate twin-band emissivity mapping, since the emissivity in the two bands would be closer in actual value. This might decrease the emissivity component of land surface temperature error to below 1 C. A three-band sensor with an appropriate emissivity calculation technique might also be developed for the TIROS satellite system.

Fourth, the positional accuracy of the ELPs needs to be improved to allow a one-step, ELP-based geographic correction

of the AVHRR images that is sufficiently accurate to meet most user's standards for inclusion in a GIS. Highly accurate orbital telemetry, such as that produced by the current Global Positioning System (GPS) satellites, is within the capability of existing technology. Refinement of TIROS satellite hardware to achieve an ELP accuracy of at least 0.5 pixel (500 m) should be implemented as soon as possible. Onboard geographic correction might be within the capability of current technology, but uncorrected images with ELPs would probably be preferred by the research community, since a variety of different map projections are in use.

## Direction of Future Research

The continuity of the NOAA TIROS AVHRR program means that a database of kilometer-resolution surface temperature patterns can be assembled for up to global coverage, and can be updated sufficiently often to monitor both seasonal changes (temperate winter season, tropical dry season) and sudden changes due to natural disasters (drought, pest/disease damage, storm, etc.) and artificial influences (crop seasons, land clearing, etc.). The value of such a long-term database was demonstrated in this study by the comparison of contemporary (1989-1993) temperature patterns from AVHRR images with those of historical (1979) HCMM images, which confirmed the long-term surface temperature pattern impacts due to hydrologic disturbance of wetlands, and the short-term impacts caused by drought, freeze, and hurricane. A global-

coverage, kilometer-resolution, surface temperature dataset with continuity over a time scale of decades would be of particular interest to climatological researchers. Many hydrological and engineering studies would necessitate regional datasets over a time scale of months or even years. Processing techniques such as those described in this study would allow the production of GIS-compatible, quantitative datasets that could be shared among these researchers.

# GLOSSARY

APT--Automatic Picture Transmission; a type of TIROS satellite analog transmission of AVHRR image data for direct reception.

AST--afternoon surface temperature, measured near 1500 h LST.

AVHRR--Advanced Very High Resolution Radiometer; a sensor aboard the NOAA TIROS satellites.

CCT--computer compatible tape.

CWN--central wave number (for a sensor band).

DATV--diurnal air temperature variation; a quantity used in normalization of DSTV measured for vegetated soil on different sites and dates.

DEP--Department of Environmental Protection; a state agency.

DN--digital number (unitless).

DSTV--diurnal surface temperature variation; the difference between AST and NST.

EAA--Everglades Agricultural Area.

ELP--Earth location point; a type of positional data included in NOAA LAC image CCTs.

EOS--Earth Observing System; an international satellite program in which NASA and NOAA are participating.

EPCHC--Environmental Protection Commission of Hillsborough County.

EST--Eastern Standard Time.

ET--evapotranspiration.

FGFFC--Florida Game and Freshwater Fish Commission.

GAC--Global Area Coverage; a type of NOAA-archived AVHRR image.

GCP--ground control point; a type of positional data obtained from digitized maps.

GIS--geographic information system; a combination of software and geographically referenced database allowing sophisticated data manipulation and analysis.

GOES--Geostationary Operational Environmental Satellite; a geostationary-orbiting type of NOAA weather satellite.

GPS--Global Positioning System; a satellite-based surveying system operated by the United States Department of Defense.

GVI--Global Vegetation Index; the standard form of scaled NDVI used in NOAA vegetation index image products.

HCMM--Heat Capacity Mapping Mission; a NASA research satellite.

HRPT--High Resolution Picture Transmission; a type of TIROS satellite digital transmission of AVHRR image data for direct reception.

IFOV--instantaneous field of view (of a sensor).

IRS--Indian Remote Sensing satellite, an Indian observational satellite system.

LAC--Local Area Coverage; a type of NOAA-archived AVHRR image.

Landsat--an American observational satellite system.

LST--Local Solar Time (different from EST).

LWIR--longwave thermal-infrared; a wavelength band provided by AVHRR bands 4 and 5.

Meteor--a polar-orbiting type of Russian weather satellite.

MWIR--midwave thermal-infrared; a wavelength band provided by AVHRR band 3.

N--north macroclimate zone.

NASA--National Aeronautics and Space Administration; a federal agency.

NDVI--normalized difference vegetation index.

NESDIS--National Environmental Satellite Data Information Service; a federal agency.

Nimbus-7--a NASA weather and research satellite.

NOAA--National Oceanic and Atmospheric Administration; a federal agency.

NSSDC--National Space Science Data Center.

NST--night surface temperature, measured near 0300 h LST.

NWFWMD--Northwest Florida Water Management District; a state agency.

P--panhandle macroclimate zone.

PC--personal computer.

PCDEM--Pinellas County Department of Environmental Management.

Pixel--picture element; the smallest spatial unit of a raster GIS.

RMS--root-mean-square (error).

RSAL--Remote Sensing Application Laboratory, at the University of Florida Agricultural Engineering Department.

S--south macroclimate zone.

SFWMD--South Florida Water Management District; a state agency.

SJRWMD--St. Johns River Water Managment District; a state agency.

SPOT--Systeme Probatoire de l'Observation de la Terre; a French observational satellite system.

SRWMD--Suwannee River Water Management District; a state agency.

SWFWMD--Southwest Florida Water Management District; a state agency.

SWIR--shortwave infrared; a wavelength band provided by AVHRR band 2.

TIROS--Television Infrared Observation Satellite; a polar-orbiting type of NOAA weather satellite.

TM--Thematic Mapper; a sensor aboard the Landsat-5 satellite.

USGS--United States Geological Survey; a federal agency.

VISSR--Vertical Infrared Spin-Scan Radiometer; a sensor aboard the GOES satellites.

# APPENDIX A
# IMAGE DOCUMENTATION

The documentation of the AVHRR and HCMM CCT image data used in this study is given below; image-processing and accuracy analysis details for individual images are given in Table 140. All AVHRR images had 5 bands of 10-bit data with a nominal at-nadir spatial resolution of 1.1 km. Nighttime images had no usable band 1 (red) or 2 (near-infrared) data. Band 3 (midwave thermal-infrared) was used to browse the images prior to extracting the Florida portion, since it gives a reasonable delineation of the land/water boundary under both daytime and nighttime conditions. The 1992 winter images contained cloud contamination in the north zone; the 1989 winter images contained cloud contamination in the south zone. These complementary images together provided cloud-free winter coverage for the entire state. The single pair of 1993 spring images were of sufficient quality to provide cloud-free spring coverage for the entire state.

All HCMM images had 2 bands of 8-bit data radiometrically calibrated and scaled by NASA. The nominal at-nadir spatial resolution of the thermal-infrared band is 600 m, that of the panchromatic band is 500 m. Nighttime images had no usable panchromatic band data. The panhandle zone was not covered by the HCMM images.

Table 140. Image accuracy evaluation details.

| Date (mm-dd-yy) | Start time (h EST) | Surface model order[1] | Spatial rms error[2] (km) | Kinetic temperature error (C) | |
|---|---|---|---|---|---|
| | | | | valid-ation[3] | verifi-cation[4] |
| AVHRR images | | | | | |
| 12-14-89 | 0240 | 2 (102) | 1.13 | 1.1 | 2.5 |
| 12-14-89 | 1405 | 2 (117) | 1.17 | 0.4 | 1.2 |
| 12-12-92 | 0806 | 3 (86) | 1.20 | 0.0 | 3.4 |
| 12-12-92 | 1523 | 3 (90) | 1.15 | 0.0 | 2.1 |
| 04-11-93 | 0454 | 2 (81) | 1.09 | 0.7 | 0.4 |
| 04-11-93 | 1617 | 2 (115) | 0.88 | 0.7 | 1.6 |
| HCMM images | | | | | |
| 02-01-79 | 0219 | 3 (73) | 1.19 | --- | --- |
| 02-03-79 | 1347 | 3 (73) | 1.19 | --- | --- |

[1] Order of global polynomial surface model for the second-stage geographic correction; the number of GCPs used is in parentheses. For HCMM images, there was only a single, GCP-based, geographic correction.

[2] The rms error of the second-stage geographic correction. For HCMM images, there was only a single, GCP-based, geographic correction.

Table 140--continued.

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[3] Average error from comparison of image kinetic temperatures to the set of water-body temperatures that were used to calculate the atmospheric correction for the image. For the historical HCMM images, there were no water-body temperature stations.

[4] Average error from comparison of image kinetic temperatures to the set of water-body temperatures that were not used to calculate the atmospheric correction for the image. For the historical HCMM images, there were no water-body temperature stations.

Spring 1993 Afternoon Image

| | |
|---|---|
| Image type: | AVHRR (LAC level 1b) |
| Date: | 04-11-93 |
| Time: | 1617 to 1630 h EST |
| Satellite: | NOAA-11 |
| Pass type: | Ascending (inverted image) |
| Orbit No.: | 23431 |
| NESDIS order no.: | 932689 |
| Tape density: | 1600 bpi |
| NOAA tape designation: | NSS.HRPT.NH.D93101.S2117.E2130.<br>B2343131.WI |
| Processing block ID: | 2343131 |

Spring 1993 Nighttime Image

| | |
|---|---|
| Image type: | AVHRR (LAC level 1b) |
| Date: | 04-11-93 |
| Time: | 0454 to 0505 h EST |
| Satellite: | NOAA-11 |
| Pass type: | Descending (non-inverted image) |
| Orbit No.: | 23424 |
| NESDIS order no.: | 933132 |
| Tape density: | 1600 bpi |
| NOAA tape designation: | NSS.HRPT.NH.D93101.S0954.E1005.<br>B2342424.WI |
| Processing block ID: | 2342424 |

<u>Winter 1992 Afternoon Image</u>

| | |
|---|---|
| Image type: | AVHRR (LAC level 1b) |
| Date: | 12-12-92 |
| Time: | 1523 to 1536 h EST |
| Satellite: | NOAA-11 |
| Pass type: | Ascending (inverted image) |
| Orbit No.: | 21736 |
| NESDIS order no.: | 933132 |
| Tape density: | 1600 bpi |
| NOAA tape designation: | NSS.HRPT.NH.D92347.S2023.E2036.<br>B2173636.WI |
| Processing block ID: | 2173636 |

<u>Winter 1992 Nighttime Image</u>

| | |
|---|---|
| Image type: | AVHRR (LAC level 1b) |
| Date: | 12-12-92 |
| Time: | 0806 to 0819 h EST |
| Satellite: | NOAA-12 |
| Pass type: | Descending (non-inverted image) |
| Orbit No.: | 08212 |
| NESDIS order no.: | 933132 |
| Tape density: | 1600 bpi |
| NOAA tape designation: | NSS.HRPT.ND.D92347.S1306.E1319.<br>B0821212.WI |
| Processing block ID: | 0821212 |

Winter 1989 Afternoon Image

| | |
|---|---|
| Image type: | AVHRR (LAC level 1b) |
| Date: | 12-14-89 |
| Time: | 1405 to 1418 h EST |
| Satellite: | NOAA-11 |
| Pass type: | Ascending (inverted image) |
| Orbit No.: | 6295 |
| NESDIS order no.: | 923479 |
| Tape density: | 1600 bpi |
| NOAA tape designation: | NSS.HRPT.NH.D89348.S1905.E1918.<br>B0629595.WI |
| Processing block ID: | 0629595 |

Winter 1989 Nighttime Image

| | |
|---|---|
| Image type: | AVHRR (LAC level 1b) |
| Date: | 12-14-89 |
| Time: | 0240 to 0253h EST |
| Satellite: | NOAA-11 |
| Pass type: | Descending (non-inverted image) |
| Orbit No.: | 6288 |
| NESDIS order no.: | 923479 |
| Tape density: | 1600 bpi |
| NOAA tape designation: | NSS.HRPT.NH.D89348.S0740.E0753.<br>B0628888.WI |
| Processing block ID: | 0628888 |

Winter 1979 Nighttime Image

| | |
|---|---|
| Image type: | HCMM (NASA calibrated and scaled) |
| Date: | 02-01-79 |
| Time: | 0219h EST |
| Satellite: | HCMM |
| Pass type: | Descending (non-inverted image) |

Winter 1979 Afternoon Image

| | |
|---|---|
| Image type: | HCMM (NASA calibrated and scaled) |
| Date: | 02-03-79 |
| Time: | 1347h EST (approx.) |
| Satellite: | HCMM |
| Pass type: | Descending (non-inverted image) |

APPENDIX B
WATER-BODY TEMPERATURE MEASUREMENT STATIONS

Details are provided here concerning the near-surface water-body temperature measurement stations (see Figure 1). These measurements are taken by calibrated thermistors at 0.5 m depth, and are reported to the nearest 0.1 C.

1. Lake Okeechobee North Tower (DBHYDRO DBKEY number L002) is operated by the SFWMD. It is located at 521,067 m east and 2,995,730 m north (UTM zone 17 format); it corresponds in this GIS to the pixel at element 709 and line 589.

2. Lake Okeechobee West Tower (DBHYDRO DBKEY number L005) is operated by the SFWMD. It is located at 502,260 m east and 2,981,776 m north (UTM zone 17 format); it corresponds in this GIS to the pixel at element 690 and line 603.

3. Lake Okeechobee South Tower (DBHYDRO DBKEY number L006) is operated by the SFWMD. It is located at 521,006 m east and 2,966,626 m north (UTM zone 17 format); it corresponds in this GIS to the pixel at element 709 and line 618.

4. Lake Apopka Floating Station (Clay Island facility) is operated by the SJRWMD. It is located at 438,904 m east and 3,166,425 m north (UTM zone 17 format); it corresponds in this GIS to the pixel at element 626 and line 418.

5. Lake Sampson periodic sampling by boat is performed by the SRWMD near the center of the lake. The measurements are taken at 385,299 m east and 3,311,196 m north (UTM zone 17 format); the site corresponds in this GIS to the pixel at element 573 and line 273.

6. Tampa Bay periodic sampling by boat is performed by the EPCHC near the mouth of the bay. The measurements are taken at 333,183 m east and 3,054,418 m north (UTM zone 17 format); the site corresponds to the pixel at element 521 and line 530.

# APPENDIX C
## LAND-COVER POLYGON DETAILS

Detailed descriptions are provided for the natural, agricultural, urban/industrial, and special condition land-cover polygons. Natural land-cover is shown in Figure 16, agricultural land-cover in Figure 17, and urban/industrial land-cover in Figure 18. Special condition land-cover types are distributed among Figures 16, 17, and 18. Zones are P = panhandle, N = north, and S = south (Figure 1).

Natural Land-Cover Polygons (see Figure 16)

1. Evergreen scrub (zone N); east of Sebring (from maps, aerial photographs, visits).

2. Evergreen scrub (zone N); Ocala National Forest, central area (from maps, visits).

3. Evergreen scrub (zone N); south of Marion Oaks (from maps, aerial photographs).

4. Evergreen scrub (zone S); Archbold Biological Station--a privately operated preserve (from maps, aerial photographs, visits).

5. Mixed scrub (zone P); Eglin Air Force Base, central area (from maps, aerial photographs).

6. Mixed scrub (zone N); Withlacoochee State Forest, northwest area (from maps, aerial photographs, visits).

7. Mixed scrub (zone N); Withlacoochee State Forest, central-west area (from maps, aerial photographs).

8. Mixed scrub (zone N); west of Marion Oaks (from maps, aerial photographs).

9. Mixed scrub (zone N); Ocala National Forest, Lake Dorr area (from maps, aerial photographs, visits).

10. Mixed scrub (zone N); Camp Blanding Wildlife Management Area and Gold Head Branch State Park (from maps, aerial photographs, visits).

11. Mixed scrub (zone N); Florahome/Whiteville area (from maps, aerial photographs, visits).

12. Upland mixed forest (zone P); Blackwater River State Forest (from maps, aerial photographs).

13. Upland mixed forest (zone P); Escambia County, Pineville area (from maps, aerial photographs).

14. Upland mixed forest (zone P); Apalachicola Bluffs area south of Chattahoochee (from maps, aerial photographs).

15. Upland mixed forest (zone P); Wakulla Springs State Park (from maps, aerial photographs, visits).

16. Upland mixed forest (zone N); Old Town Hammock (from maps, aerial photographs, visits).

17. Upland mixed forest (zone N); San Felasco Hammock State Preserve (from maps, aerial photographs, visits).

18. Flatwoods forest (zone P); Apalachicola National Forest, west area (from maps, aerial photographs, visits).

19. Flatwoods forest (zone P); Apalachicola National Forest, east area (from maps, aerial photographs, visits).

20. Flatwoods forest (zone N); San Pedro Bay area southeast of Perry (from maps, aerial photographs, visits).

21. Flatwoods forest (zone N); Osceola National Forest (from maps, aerial photographs, visits).

22. Flatwoods forest (zone S); Gator Slough/Yucca Pen Creek area north of Cape Coral (from maps, aerial photographs).

23. Flatwoods forest (zone S); C. M. Webb Wildlife Management Area (from maps, aerial photographs).

24. Flatwoods forest (zone S); J. W. Corbett Wildlife Management Area (from maps, aerial photographs, visits).

25. Flatwoods forest (zone S); Hendry County, Keri area (from maps, aerial photographs, visits).

26. Flatwoods forest (zone S); Glades County, Rainey Slough area (from maps, aerial photographs, visits).

27. Rockland hammock (zone N); Levy County, Rocky Hammock/ Rosewood area (from maps, aerial photographs, visits).

28. Rockland hammock (zone N); Levy County, Gulf Hammock--northwest area (from maps, aerial photographs, visits).

29. Rockland hammock (zone N); Levy County, Cedar Hammock/ Lebanon area (from maps, aerial photographs, visits).

30. Rockland hammock (zone S); Everglades National Park, Long Pine Key (from maps, aerial photographs, visits).

31. Rockland hammock (zone S); south of Homestead (from maps, aerial photographs).

32. Rockland hammock (zone S); Big Cypress National Preserve, Bear Island area (from maps, aerial photographs, visits).

33. Coastal hammock (zone P); St. Vincent National Wildlife Refuge (from maps, aerial photographs, visits).

34. Coastal hammock (zone P); Beacon Beach area (from maps, aerial photographs).

35. Coastal hammock (zone N); Cape Canaveral Air Force Station (from maps, aerial photographs).

36. Coastal hammock (zone N); Cumberland Island National Seashore--Georgia (from maps, visits).

37. Coastal hammock (zone N); Big Bend, Econfina/Fenholloway River area (from maps, aerial photographs).

38. Coastal hammock (zone N); Big Bend, Blue Springs/ Steinhatchee area (from maps, aerial photographs).

39. Coastal hammock (zone N); Merritt Island National Wildlife Refuge, north area (from maps, aerial photographs).

40. Coastal hammock (zone N); Merritt Island National Wildlife Refuge, south area (from maps, aerial photographs, visits).

41. Coastal hammock (zone N); Turnbull Hummock, north area (from maps, aerial photographs).

42. Coastal hammock (zone S); Island Bay National Wildlife Refuge (from maps, aerial photographs).

43. Coastal hammock (zone S); Jonathan Dickinson State Park (from maps, aerial photographs, visits).

44. Coastal hammock (zone S); Sanibel Island, west area, including J. N. Darling National Wildlife Refuge and Sanibel Island State Botanical Site (from maps, aerial photographs, visits).

45. Coastal hammock (zone S); Everglades National Park, Cape Sable/Flamingo/Snake Bight area (from maps, aerial photographs).

46. Evergreen hardwood swamp (zone N); LaFayette County, Mallory Swamp (from maps, aerial photographs).

47. Evergreen hardwood swamp (zone N); O'Leno State Park (from maps, aerial photographs, visits).

48. Evergreen hardwood swamp (zone S); Fakahatchee Strand State Preserve (from maps, aerial photographs, visits).

49. Deciduous hardwood swamp (zone P); Apalachicola River floodplain (from maps, aerial photographs, visits).

50. Deciduous hardwood swamp (zone P); Escambia River floodplain (from maps, aerial photographs).

51. Deciduous hardwood swamp (zone P); Choctawhatchee River floodplain (from maps, aerial photographs).

52. Deciduous hardwood swamp (zone N); Hillsborough River State Park (from maps, aerial photographs, visits).

53. Deciduous hardwood swamp (zone N); Hontoon Island State Park (from maps, aerial photographs, visits).

54. Cypress swamp (zone N); Green Swamp Wildlife Management Area (from maps, aerial photographs).

55. Cypress swamp (zone N); Deep Creek/McKenzie Islands area east of Deland (from maps, aerial photographs, visits).

56. Cypress swamp (zone N); Tiger Bay/Dukes Islands area east of Deland (from maps, aerial photographs).

57. Cypress swamp (zone S); Corkscrew Swamp Sanctuary area (from maps, aerial photographs, visits).

58. Cypress swamp, dwarf (zone S); Big Cypress National Preserve, Monroe Station area (from maps, aerial photographs).

59. Cypress swamp, dwarf (zone S); Big Cypress National Preserve, Fiftymile Bend area (from maps, aerial photographs).

60. Cypress swamp, dwarf (zone S); Big Cypress National Preserve, central area (from maps, aerial photographs, visits).

61. Bay swamp (zone P); Eglin Air Force Base, East Bay Swamp (from maps, aerial photographs).

62. Bay swamp (zone P); Eglin Air Force Base, Alabama Hollow area (from maps, aerial photographs).

63. Bay swamp (zone P); Mulatto Bayou area south of Bagdad (from maps, aerial photographs).

64. Bay swamp (zone N); Chassahowitzka Swamp, from Homosassa to Weeki-Wachee (from maps, aerial photographs, visits).

65. Mixed swamp (zone N); Okeefenokee National Wildlife Refuge, north of Suwannee River--Georgia (from maps, visits).

66. Mixed swamp (zone N); Withlacoochee State Forest, southeast area (from maps, aerial photographs).

67. Mixed swamp (zone N); Levy County, Devil's Hammock (from maps, aerial photographs, visits).

68. Mixed swamp (zone N); Hull Cypress Swamp/Bennett Swamp area west of Daytona Beach (from maps, aerial photographs, visits).

69. Mixed swamp (zone N); Spruce Creek Swamp area south of Daytona Beach (from maps, aerial photographs).

70. Mixed swamp (zone N); Wekiva Swamp (from maps, aerial photographs, visits).

71. Mixed swamp (zone S); Big Cypress National Preserve, north of Alligator Alley (from maps, aerial photographs, visits).

72. Mangrove swamp (zone S); Everglades National Park, Ten-Thousand Islands area (from maps, aerial photographs).

73. Mangrove swamp (zone S); Everglades National Park, Whitewater Bay/Shark River mouth area (from maps, aerial photographs).

74. Mangrove swamp (zone S); Everglades National Park, northwest Cape Sable area (from maps, aerial photographs).

75. Evergreen shrubby marsh (zone S); Big Cypress Seminole Indian Reservation, northeast area (from maps, aerial photographs, visits).

76. Deciduous shrubby marsh (zone S); Corkscrew Swamp Sanctuary, west of Lake Trafford (from maps, aerial photographs).

77. Marsh (zone P); Lake Iamonia (from maps, aerial photographs).

78. Marsh (zone N); Tosohatchee State Preserve (from maps, aerial photographs, visits).

79. Marsh (zone N); Payne's Prairie State Preserve (from maps, aerial photographs, visits).

80. Marsh (zone N); Tsala Apopka Lake (from maps, aerial photographs, visits).

81. Marsh (zone S); Lake Okeechobee, Moonshine Bay area (from maps, aerial photographs, visits).

82. Marsh (zone S); Water Conservation Area Number 2 (from maps, aerial photographs.

83. Marsh (zone S); Deep Everglades, Little Doctor Village/ Custard Apple Hammock area (from maps, aerial photographs).

84. Marsh, wet-prairie (zone S); Everglades National Park, southwest of Long Pine Key (from maps, aerial photographs).

85. Marsh, wet-prairie (zone S); Everglades National Park, west of Homestead (from maps, aerial photographs).

86. Saltmarsh (zone P); St. Marks National Wildlife Refuge (from maps, aerial photographs, visits).

87. Saltmarsh (zone N); Waccasassa Bay area (from maps, aerial photographs, visits).

88. Saltmarsh (zone N); Nassau River mouth/Amelia River area (from maps, aerial photographs).

89. Saltmarsh (zone N); Chassahowitzka National Wildlife Refuge (from maps, aerial photographs, visits).

90. Saltmarsh (zone N); St. Johns River mouth/Sisters Creek area (from maps, aerial photographs, visits).

91. Saltmarsh, brackish (zone S); Everglades National Park, Joe Bay area (from maps, aerial photographs).

Agricultural Land-Cover Polygons (see Figure 17)

1. Row-crops, on flatwoods sand (zone S); Palm Beach County, area west of Boynton Beach (from maps, aerial photographs, visits).

2. Row-crops, on coastal sand (zone S); Lee County, Truckland area (from maps, aerial photographs, visits).

3. Row-crops, on marly rockland (zone S); Collier County, Henderson Creek area (from maps, aerial photographs).

4. Row-crops, on muck (zone N); Lake/Orange Counties, between Zellwood and Lake Apopka (from maps, aerial photographs, visits).

5. Row-crops, on muck (zone N); Highlands County, Sunvale area (from maps, aerial photographs, visits).

6. Pasture/range, on flatwoods sand (zone P); Gulf County, northwest area (from maps, aerial photographs).

7. Pasture/range, on flatwoods sand (zone N); Osceola/Brevard Counties, area east of Holopaw (from maps, aerial photographs).

8. Pasture/range, on flatwoods sand (zone N); Okeechobee County, south area (from maps, aerial photographs, visits).

9. Pasture/range, on flatwoods sand (zone N); Highlands County, southeast area (from maps, aerial photographs, visits).

10. Pasture/range, on flatwoods sand (zone N); Polk County, northwest area (from maps, aerial photographs).

11. Pasture/range, on flatwoods sand (zone N); Osceola/Okeechobee Counties, area west of Yeehaw Junction (from maps, aerial photographs, visits).

12. Pasture/range, on flatwoods sand (zone S); Hendry County, east area (from maps, aerial photographs, visits).

13. Pasture/range, on flatwoods sand (zone S); Sarasota/Manatee Counties; area south of Lake Myakka (from maps, aerial photographs).

14. Pasture/range, on flatwoods sand (zone S); DeSoto County, southeast area (from maps, aerial photographs, visits).

15. Pasture/range, on flatwoods sand (zone S); Lee County, area southeast of Fort Myers (from maps, aerial photographs, visits).

16. Pasture/range, on sandy rockland (zone S); Hendry County, Sunnyland Station area (from maps, aerial photographs, visits).

17. Pasture/range, on sandy rockland (zone S); Broward County, Andytown area (from maps, aerial photographs, visits).

18. Pasture/sod, on muck (zone N); Highlands County, area south of Lake Istokpoga (from maps, aerial photographs, visits).

19. Pasture/sod, on muck (zone N); Indian River County, area northeast of Blue Cypress Lake (from maps, aerial photographs).

20. Pasture/sod, on muck (zone S); Hendry County, southeastd area (from maps, aerial photographs).

21. Pasture/sod, on muck (zone S); Broward County, area west of Hollywood (from maps, aerial photographs).

22. Citrus orchard, on deep sand (zone N); Polk County, Lake Henry Ridge (from maps, aerial photographs).

23. Citrus orchard, on deep sand (zone N); Polk County, middle portion of Lake Wales Ridge (from maps, aerial photographs, visits).

24. Citrus orchard, on deep sand (zone S); Highlands County, lower portion of Lake Wales Ridge (from maps, aerial photographs, visits).

25. Citrus orchard, on upland loamy sand (zone N); Pasco County, lower portion of Brooksville Ridge (from maps, aerial photographs, visits).

26. Citrus orchard, on flatwoods sand (zone N); St. Lucie County, Indian River area (from maps, aerial photographs, visits).

27. Citrus orchard, on flatwoods sand (zone N); DeSoto County, east of Arcadia (from maps, aerial photographs, visits).

28. Citrus orchard, on flatwoods sand (zone S); Martin County, upper portion of Allapattah Flats (from maps, aerial photographs, visits).

29. Citrus orchard, on flatwoods sand (zone S); Palm Beach County, lower portion of Allapattah Flats (from maps, aerial photographs, visits).

30. Mixed agriculture, on deep sand (zone P); Jackson County, north of Marianna (from maps, aerial photographs).

31. Mixed agriculture, on deep sand (zone N); Alachua County, west of highway US-41 (from maps, aerial photographs, visits).

32. Mixed agriculture, on deep sand (zone N); Gilchrist County, Bell Ridge (from maps, aerial photographs, visits).

33. Mixed agriculture, on deep sand (zone N); Sumter County, northeast of Wildwood (from maps, aerial photographs, visits).

34. Mixed agriculture, on upland loamy sand (zone P); Jackson County, northeast of Chipley (from maps, aerial photographs, visits).

35. Mixed agriculture, on upland loamy sand (zone N); Suwannee County area (from maps, aerial photographs, visits).

36. Mixed agriculture, on upland loamy sand (zone N); Marion County, north-central area (from maps, aerial photographs, visits).

37. Mixed agriculture, on upland loamy sand (zone N); Sumter County, Bushnell area (from maps, aerial photographs, visits).

38. Mixed agriculture, on flatwoods sand (zone N); St. Johns County, Hastings/Spuds/Tocoi area (from maps, aerial photographs, visits).

39. Mixed agriculture, on flatwoods sand (zone N); Hillsborough County, Gibsonton/Ruskin area (from maps, aerial photographs, visits).

40. Mixed agriculture, on flatwoods sand (zone N); Sarasota/ Manatee Counties, Fruitville area (from maps, aerial photographs, visits).

41. Mixed agriculture, on flatwoods sand (zone S); Glades County, west of Moore Haven (from maps, aerial photographs, visits).

42. Mixed agriculture, on flatwoods sand (zone S); Collier County, Felda area north and west of Immokalee (from maps, aerial photographs, visits).

43. Mixed agriculture, on sandy rockland (zone N); Alachua County, between interstate highway I-75 and highway US-41 (from maps, aerial photographs, visits).

44. Mixed agriculture, on sandy rockland (zone N); Levy/ Gilchrist Counties, Trenton area (from maps, aerial photographs, visits).

45. Mixed agriculture, on sandy rockland (zone N); Levy County, south of Chiefland (from maps, aerial photographs, visits).

46. Mixed agriculture, on sandy rockland (zone S); Dade County, west of Homestead (from maps, aerial photographs, visits).

47. Mixed agriculture, on sandy rockland (zone S); Lee County, east of Koreshan (from maps, aerial photographs).

48. Mixed agriculture, on marly rockland (zone S); Collier County, southwest of Immokalee (from maps, aerial photographs, visits).

49. Mixed agriculture, on muck (zone S); Palm Beach County, Everglades Agricultural Area east of Clewiston (from maps, aerial photographs, visits).

50. Mixed agriculture, on muck (zone S); Glades County; Everglades Agricultural Area northwest of Clewiston (from maps, aerial photographs, visits).

<u>Urban/Industrial Land-Cover Polygons</u> (see Figure 18)

1. Suburb, on deep sand (zone N); Marion County, central area of Marion Oaks (from maps, aerial photographs).

2. Suburb, on deep sand (zone N); Marion County, north area of Marion Oaks (from maps, aerial photographs).

3. Suburb, on deep sand (zone N); Putnam Co., Satsuma (from maps, aerial photographs, visits).

4. Suburb, on deep sand (zone N); Marion County, Silver Springs Shores (from maps, aerial photographs, visits).

5. Suburb, on deep sand (zone N); Levy/Marion Counties, Bronson/Rainbow Lakes Estates/Williston Highlands area (from maps, aerial photographs, visits).

6. Suburb, on upland loamy sand (zone N); Citrus County, Citrus Springs (from maps, aerial photographs, visits).

7. Suburb, on flatwoods sand (zone N); Brevard County, Palm Bay (from maps, aerial photographs).

8. Suburb, on flatwoods sand (zone S); Lee County, Leehigh Acres (from maps, aerial photographs, visits).

9. Suburb, on coastal sand (zone P); Walton County, Seagrove Beach area (from maps, aerial photographs).

10. Suburb, on coastal sand (zone P); Santa Rosa County, Bal Alex area (from maps, aerial photographs).

11. Suburb, on coastal sand (zone N); Pasco County, Jasmine Estates (from maps, aerial photographs, visits).

12. Suburb, on sandy rockland (zone N); Levy/Citrus Counties, Sulphur Spring/Inglis area (from maps, aerial photographs, visits).

13. Suburb, on marly rockland (zone S); Collier County, Golden Gate (from maps, aerial photographs).

14. Platted suburb, on flatwoods sand (zone N); St. Johns County, Flagler Estates (from maps, visits).

15. Finger-canal suburb, on flatwoods sand (zone S); Lee County, Cape Coral (from maps, aerial photographs, visits).

16. Finger-canal suburb, on flatwoods sand (zone S); Charlotte County, Port Charlotte (from maps, aerial photographs).

17. Finger-canal suburb, on coastal sand (zone S); Collier County, Marco Island (from maps, aerial photographs).

18. Golf-course suburb, on flatwoods sand (zone N); Pinellas County, Dunedin/Clearwater area (from maps, aerial photographs, visits).

19. Golf-course suburb, on flatwoods sand (zone S); Palm Beach County, west of Boca Raton (from maps, aerial photographs).

20. Golf-course suburb, on flatwoods sand (zone S); Broward County, North Lauderdale/Margate area (from maps, aerial photographs).

21. Golf-course suburb, on sandy rockland (zone S); Palm Beach County, west of Boca Raton (from maps, aerial photographs).

22. Golf-course suburb, on sandy rockland (zone S); Lee County, Fort Myers Villas (from maps, aerial photographs).

23. Indian reservation, on flatwoods sand (zone S); Glades County, Brighton Indian Reservation (from maps, aerial photographs, visits).

24. Urban center, on deep sand (zone P); Pensacola (from maps, aerial photographs).

25. Urban center, on deep sand (zone P); Tallahassee, southwest area (from maps, aerial photographs, visits).

26. Urban center, on deep sand (zone N); Tampa, east area (from maps, aerial photographs, visits).

27. Urban center, on deep sand (zone N); Lakeland (from maps, aerial photographs, visits).

28. Urban center, on deep sand (zone N); Orlando, north area (from maps, aerial photographs, visits).

29. Urban center, on upland loamy sand (zone P); Tallahassee, northeast area (from maps, aerial photographs, visits).

30. Urban center, on upland loamy sand (zone N); Ocala (from maps, aerial photographs, visits).

31. Urban center, on upland loamy sand (zone N); Gainesville (from maps, aerial photographs, visits).

32. Urban center, on flatwoods sand (zone P); Panama City (from maps, aerial photographs, visits).

33. Urban center, on flatwoods sand (zone N); St. Petersburg (from maps, aerial photographs, visits).

34. Urban center, on flatwoods sand (zone N); Tampa, west area (from maps, aerial photographs, visits).

35. Urban center, on flatwoods sand (zone N); Orlando, south-central area (from maps, aerial photographs, visits).

36. Urban center, on flatwoods sand (zone N); Jacksonville (from maps, aerial photographs, visits).

37. Urban center, on flatwoods sand (zone N); Daytona Beach (from maps, aerial photographs, visits).

38. Urban center, on flatwoods sand (zone N); Bradenton (from maps, aerial photographs, visits).

39. Urban center, on flatwoods sand (zone S); Fort Myers (from maps, aerial photographs, visits).

40. Urban center, on flatwoods sand (zone S); Immokalee (from maps, aerial photographs, visits).

41. Urban center, on flatwoods sand (zone S); West Palm Beach (from maps, aerial photographs, visits).

42. Urban center, on coastal sand (zone P); Apalachicola (from maps, aerial photographs, visits).

43. Urban center, on coastal sand (zone P); Port St. Joe (from maps, aerial photographs, visits).

44. Urban center, on coastal sand (zone P); Destin (from maps, aerial photographs).

45. Urban center, on sandy rockland (zone N); Williston (from maps, aerial photographs, visits).

46. Urban center, on sandy rockland (zone S); Fort Lauderdale/Miami (from maps, aerial photographs, visits).

47. Urban center, on sandy rockland (zone S); Naples (from maps, aerial photographs, visits).

48. Urban center, on muck (zone S); Belle Glade (from maps, aerial photographs, visits).

49. Phosphate mine, on flatwoods sand (zone N); Polk County, Bone Valley area (from maps, aerial photographs, visits).

50. Phosphate mine, on flatwoods sand (zone N); Hamilton County, east area (from maps, aerial photographs, visits).

51. Titanium mine, on deep sand (zone N); Clay County; northwest of Kingsley Lake (from maps, aerial photographs).

52. Titanium mine, on deep sand (zone N); Clay County; southwest of Kingsley Lake (from maps, aerial photographs).

<u>Special Land-Cover Condition Polygons</u>

S-1. Bay swamp under drought condition (zone N); Bradford County, Santa Fe Swamp (from maps, aerial photographs, visits). See Figure 16.

S-2. Bay swamp under drought condition (zone N); Columbia County, Sandlin Bay (from maps, aerial photographs). See Figure 16.

S-3. Mixed swamp under drought condition (zone N); Baker County, Pinhook Swamp (from maps, aerial photographs). See Figure 16.

S-4. Mixed swamp under drought condition (zone N); Okefenokee National Wildlife Refuge, south of Suwannee River --Georgia (from maps, visits). See Figure 16.

S-5. Citrus orchard on deep sand, under freeze-damaged condition (zone N); Lake County, upper area of Lake Wales Ridge (from maps, aerial photography, visits). See Figure 17.

S-6. Urban center, on sandy rockland (zone S) under hurricane-damaged condition; Dade County, Homestead/ Leisure City area (from maps, aerial photographs). See Figure 18.

S-7. Dwarf-cypress swamp under disturbed condition (zone S); Collier County, Golden Gate Estates area (from maps, aerial photographs, visits). See Figure 16.

S-8. Marsh under disturbed condition (zone S); Palm Beach County, Holey Land/Rotenberger Wildlife Management Areas (from maps, aerial photographs). See Figure 16.

S-9. Marsh under heavily disturbed condition (zone S); Palm Beach County, Water Conservation Area Number 1--Loxahatchee National Wildlife Refuge (from maps, aerial photographs, visits). See Figure 16.

S-10. Flatwoods forest under exotic forest invasion condition (zone S); Palm Beach County, West Green Acres area (from maps, aerial photographs, visits). See Figure 16.

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## BIOGRAPHICAL SKETCH

Jonathan David Jordan was born in Dunedin, Florida, in 1962. He attended Thomas Jefferson High School in Tampa, Florida. He has earned a B.S., M.E., and Ph.D., all in agricultural engineering, at the University of Florida. He has been employed in aquaculture, construction materials testing, and as a graduate research assistant. Several of his research articles relating to remote sensing and image-processing have been published in scholarly journals; he has also made presentations on these topics at national and international meetings.

While at the University of Florida, he has been a member of the American Society of Agricultural Engineers (ASAE), the American Society for Photogrammetry and Remote Sensing (ASPRS), the Society of Photo-Optical Instrumentation Engineers (SPIE), the American Geophysical Union (AGU), the Southeast Geological Society (SEGS), the American Water Resources Association (AWRA), the Society of American Foresters (SAF), the Gamma Sigma Delta Agricultural Honor Society, and the Florida Fossil Horse Society. He has served the local chapter of the Alpha Epsilon Agricultural Engineering Honorary Society as vice-president (1986), treasurer (1987), and president (1988).

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Sun F. Shih

Sun F. Shih, Chairman
Professor of Agricultural Engineering

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Jerome J. Gaffney

Jerome J. Gaffney
Associate Professor of Agricultural Engineering

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Dorota Z. Haman

Dorota Z. Haman
Associate Professor of Agricultural Engineering

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Edward P. Lincoln

Edward P. Lincoln
Associate Professor of Agricultural Engineering

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Byron E. Ruth
Professor of Civil
Engineering

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

George H. Snyder
Professor of Soil and Water
Science

This dissertation was submitted to the Graduate Faculty of the College of Engineering and to the Graduate School and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

December 1994

Winfred M. Phillips
Dean, College of Engineering

Karen A. Holbrook
Dean, Graduate School